Assessment of the Impacts of Various Grazing Management Strategies on Southern Minnesota Stream Channels

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Abstract

Stream riparian corridors are inherent to many farms in southern Minnesota. They are complex and diverse ecosystems, provide transportation for drainage from agricultural fields, and contribute to the quality of the larger watershed to which they belong. However, much of the 3.5 million miles of rivers in the United States are impacted, with sedimentation and excess nutrients being the most significant causes of degradation. The agricultural areas of southern Minnesota commonly use stream corridors as pasture since they are generally unsuitable for crops and provide a natural source of water for livestock. Traditional methods of grazing livestock can cause reduced vegetative cover, compacted soils, water contamination, sedimentation, and eroded banks. Managing livestock by limiting the location and duration of their grazing has seen some success in reducing the impact compared to conventional grazing methods.

My research aims to further determine the impacts various grazing management strategies have had on streams. Geomorphic data from four sites across three streams are analyzed to evaluate effects of current grazing strategies and changes in grazing strategies. Grassed and wooded areas are also compared, as grazing directly influences the vegetative communities. The results suggest that both managed and grazing exclusion sites showed healthier channels than conventional grazing sites did, and that grassed bank areas contribute more to channel stability than wooded bank areas. In certain situations, managed grazing has the potential to be more beneficial to stream channel health than the prohibition of grazing.

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1. INTRODUCTION

1.1. Problem Statement

Stream riparian corridors are common on many farms in southern Minnesota. These areas are often used as pasture since they are generally unsuitable for crops and provide a natural source of water for livestock. Erosion and pollution in the stream riparian corridors is a large-scale problem in southern Minnesota. This is mainly due to human impact (Whaley, 2007). These impacts have often been attributed to nearby land use and poor riparian management as row-crop farming is the primary contributor of nonpoint source pollution in this area (Goolsby et al., 1999; Sovell et al., 2000; Magner et al., 2008).

Cattle grazing has significant impacts on the geomorphology of a river. By trampling and overgrazing streambanks, livestock can cause soil erosion, soil compaction, loss of streambank stability, and impact water quality (Buckhouse et al., 1981; Trimble, 1995; Belsky et al., 1999; Magner et al., 2008; Tufekcioglu et al., 2012; Pilon et al., 2017). When put in an enclosed pasture, livestock generally stay together and favor certain spots that have more shade, water, and vegetation. This draws them closer to the stream, causing greater destruction at certain locations (Ohmart, 1996; Grudzinski et al., 2016). The loss of riparian vegetation causes greater bare cover on stream banks, increasing erosion and the scouring of banks (Trimble, 1995; Grudzinski et al., 2016; Pilon et al., 2017). Sediment pollution in particular damages fish habitat and the trout fishing tourism industry, which is a significant part of the region's economy (Platts, 1978; Lyons et al., 2000a; Sullivan et al., 2006; Simpson et al., 2014). If riparian corridors are restored, reductions in sediment loads and other pollutants will be noticeable for many miles downstream (Sovell et al., 2000; Simon, 2002). Benefits for the landowner include better forage for the livestock, improved water quality, and long-term improvements to the land (Blanchet et al., 2000; Undersander et al., 2002).

As a solution, the exclusion of all grazing has historically been recommended (Sarr, 2002; Magner et al., 2008). This means that no grazing is permitted in an area, usually enforced using fencing. It has shown that it can result in significant improvements in vegetation and stability at sites that were previously burdened by livestock (Platts, 1978; Line et al., 2000; Batchelor et al., 2015). However, grazing exclusion may not be a long-term solution as studies have found that while some sites may quickly heal, others may recover more slowly and remain more susceptible to livestock impacts in the future, or even fail to recover due to the changes (Sarr, 2002) . Only reducing the stocking rate of a pasture is also not as effective as exclusion from the riparian corridor (Swanson et al., 2015). Other studies have shown that managed grazing methods, such as short-duration grazing or intensive rotational grazing, provide better biological and physical recovery than grazing exclusion (Lyons et al., 2000a; Sovell et al., 2000; Moechnig, 2007; Magner et al. 2008). Despite allowing some vegetation loss and hoof shear, this kind of managed grazing improves the overall composition and health of the plant community on the streambanks (Moechnig, 2007). Sections of the pasture are allowed to recover and concentrated damage is minimized by rotating the livestock around different portions of the stream corridor (Swanson et al., 2015). This idea has been around for a while, as rest and rotation systems were being proposed, as far back as the 1980's, as cheaper and more effective than exclusion methods (Kauffman and Kruger, 1984). More recently, recommendations are being made by the Minnesota Department of Agriculture to adopt managed rotational grazing systems instead (Moechnig, 2007).

Other strategies to restore reaches impacted by grazing include riparian buffer strips, fencing off riparian corridors, and revegetating and reshaping damaged banks (Lyons et al., 2000b; Platts and Wagstaff, 2011). However, these are generally expensive or complex projects. Farmers cannot always afford these large costs, and the projects cannot be applied in certain scenarios. Even after restoration is complete, reintroduction of grazing can sometimes diminish or even negate the desired effects. While there is literature related to conventional cattle grazing, managed cattle grazing, and grazing exclusion strategies for riparian area management, little data have been collected in the upper Midwestern United States on stream bank and channel responses to grazing management changes. The goal of this study is to compare specific sites that have differently managed reaches in order to examine the effects of conventional grazing, managed grazing, and grazing exclusion practices on riparian corridors of southern Minnesota streams.

Grazed pastures generally have more grassed riparian vegetation, as grazing provides a form of active management. Wooded stream banks are more common in non-grazing sites, since successional processes can take place (Rickard and Cushing, 1982; Lyons et al., 2000b). While comparing grazing strategies, different riparian bank vegetative covers can be compared as well. Grassed and wooded riparian areas have shown differences regarding stability, erosion, and habitat (Kondolf, 1993; Magilligan and McDowell, 1997; Lyons et al., 2000a; Lyons et al., 2000b; Sovell et al., 2000).

All streams are different and their situations are unique. While streams cannot be expected to have a universal response to changes, comparing riparian corridors with similar hydrology, geology, and grazing conditions may yield insight into how to better manage future similar situations (Sarr, 2002; Juracek and Fitzpatrick, 2003; Agouridis, 2005). A combination of strategies and management tools is always needed to be successful.

1.2. Research Objectives

The objectives of this study are (1) to evaluate the effects of three different grazing management methods across three different streams in southern Minnesota, and (2) compare wooded and grassed stream banks areas. Conventional grazing, managed grazing, and non-grazing sites are studied at reaches of Dobbins Creek, Sugarloaf Creek, and Elm Creek to inform the final proposal.

1.3. Research Questions

This thesis research assesses the impacts of three riparian grazing management methods on stream channels. Data from three reaches on three different streams are used to evaluate each grazing type. Channel geometries, slopes, particle size distributions, and Bank Erosion Hazard Index (BEHI) scores are compared to answer the following questions:

1. Changing grazing management of stream banks can affect not just the immediate riparian corridor, but the rest of the watershed as well. Human impacts cannot be overlooked. The landowner gives up all use of the land under the grazing exclusion strategy. Can managed grazing accomplish the desired degree of natural restoration while still allowing the land to be utilized by the farmer?

2. The history and convenience of using the conventional method of grazing has contributed to its popularity. However, literature has argued and shown the damaging effects it can have on riparian ecosystems and stream bank stability. Does this hold true for these sites and streams?

3. Traditionally, the solution applied to reaches impacted by grazing is to prohibit grazing. This eventually transforms the stream bank area to become a more wooded system. Alternatively, costly restoration projects are implemented to revegetate banks. Is a wooded or a grassed stream bank area better for channel

stability and habitat?

1.4. Research Hypotheses

The following hypotheses are formulated in response to the questions above:

1. H_0: Managed grazing will show poorer results than grazing exclusion.

   H_a: Managed grazing will show similar or better results than grazing exclusion.

2. H_0: Conventional grazing will show similar or better results compared to the other grazing types.

   H_a: Conventional grazing will show the poorest results of the three grazing types.

3. H_0: No relationship will be shown between the physical or biological health of a stream channel and the type of vegetative cover on the stream bank area.

   H_a: Streams with grassed stream bank areas will have better channel stability and habitat.

2. LITERATURE REVIEW

2.1. Stream Stability and Morphology

River stability is defined as a stream's ability to transport water and sediment over time without aggrading or degrading, and maintaining its dimension, pattern, and profile (Rosgen, 1996, 2001, 2006). Aggradation is deposition of material raising the base level of a channel and degradation is the erosion of channel beds and banks. Many factors, both natural and man-made, influence and change river stability. Some aggradation and degradation are part of natural stream processes, as the seasons shift and rainfall events vary. Most rivers are able to withstand small changes. After a small flood event or a minor man-made influence, a stable river will be able to return to its previous state. Even after large perturbations such as a large return-period flood or construction of a dam, some rivers have been known to revert back (Calow and Petts, 2009). However, in many cases of extreme human influence, rivers are unable to recover. Human causes can include land use changes, construction, and pollution. Potential natural causes include heavy rainfall events, flooding, and tectonic activity (Whaley, 2007).

How a stream reacts to changes depends greatly on its morphology: the shape of the river channel, which is mainly determined through sedimentation and erosion processes (Rosgen, 1996; Whaley, 2007;). A stream's morphology is highly variable, even within the same reach. However, a stable channel generally has a parabolic or trapezoidal shape with banks slope outwards at bankfull elevation and open up into a well-developed floodplain (Dunne and Leopold, 1978). Bankfull flow occurs when the water level overflows from the channel. Bankfull elevation is the stage at which the water leaves the channel and enters the floodplain, assuming the stream has good floodplain connectivity and is not incised (Bent and Waite, 2013). Bankfull flows occur every 1.5 to 2 years, on average, and are a major influence on a river's stability and morphology

(Rosgen, 2006). By overflowing the channel, these floods move sediment and shape not only the channel but the river valley as well. Variables that determine the form of a stream channel include volumetric discharge, water velocity, sediment supply, sediment size, channel width, channel depth, and slope (Rosgen, 2001; Trainor and Church, 2003). These characteristics are mainly determined by the climate and geology of the area, as well as upstream conditions and nearby land use (Asmus et al., 2009).

2.1.1 Rosgen Stream Classification

A river's behavior can, to a certain degree, be predicted based on its present physical, hydrologic, and geomorphic dimensions. Rosgen's stream classification system defines a stream type through four hierarchical assessments (Rosgen, 1996; 2014). Each level of assessment requires additional field measurements and provides greater detail on the stream's proper classification. Level 1 assessment is the geomorphic characterization. Streams are classified among eight major morphological categories defined by entrenchment ratio, width to depth ratio, sinuosity, slope, and landform or soil features. The channel material determines the number that follows the categorical letter. Figure 2.1 below shows what these ratios look like and what stream type is associated with them. Also shown is a flow chart illustrating the process of classifying a river using Level 1 and 2 geomorphic characterizations. This method was chosen due to its prominence in the midwestern region and widespread use in state and federal agencies (Kasprak et al., 2016).

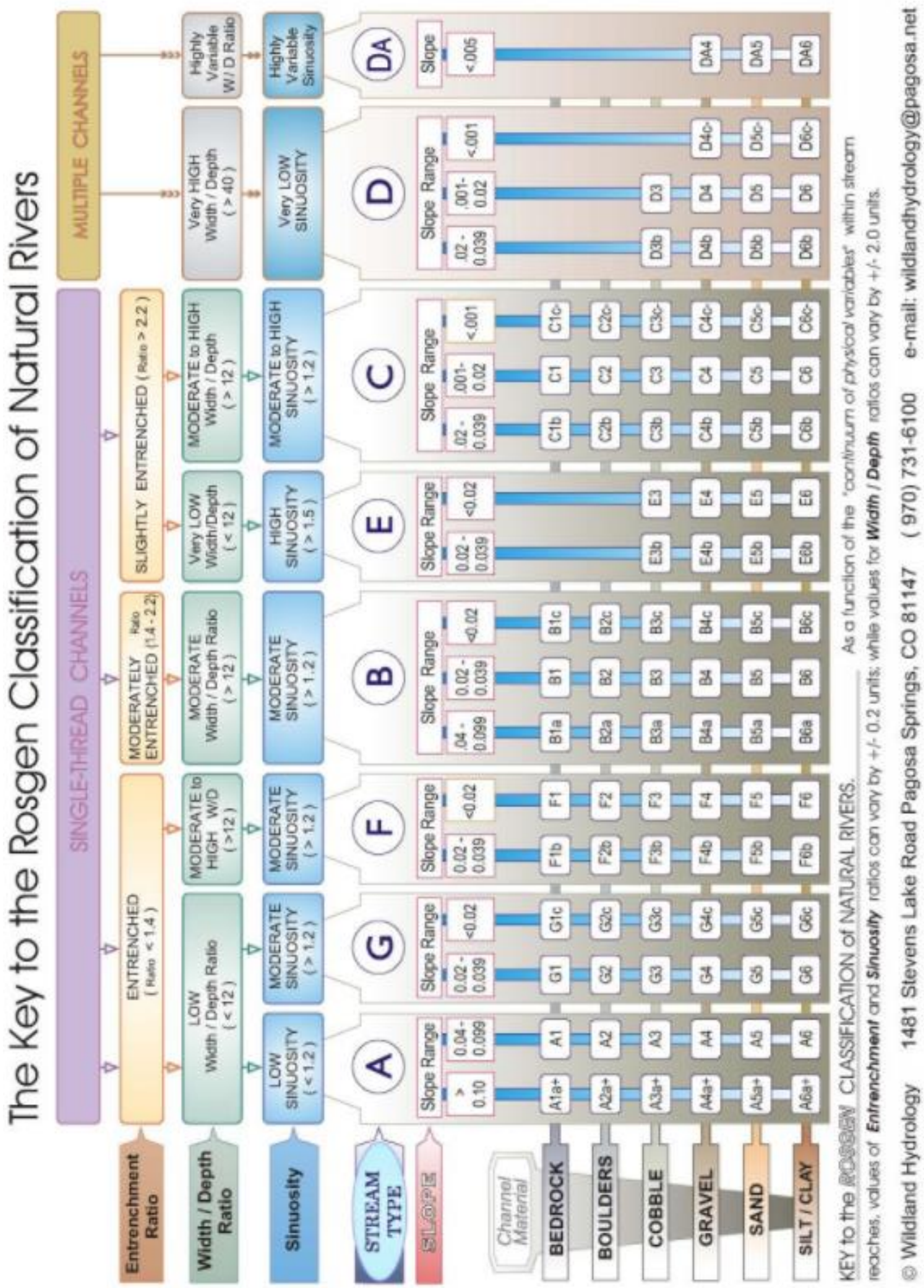

Figure 2.1. Flowchart for Rosgen Level 1 Assessment (Rosgen, 1996).

Level 1 assessment is appropriate for basic reconnaissance and categorization of streams. However, in most cases, further assessment is required.

The Level 2 assessment requires field measurements for a morphological description of the channel. These measurements include longitudinal profile, cross-sections, pebble counts, and meander geometry.

The Level 3 assessment of Rosgen's stream classification method is stream state or condition. This is also the level where predictions are made regarding the channel's response to current or potential stresses. Variables that affect channel stability are assessed and then used with specific figures, equations, and tables in order to evaluate the stability of a bank or reach.

The Level 4 assessment involves monitoring and validation on reach-specific studies. By measuring sediment, streamflow, and other variables that represent spatial and temporal scales, the predictions made from previous assessments in Level 2 and 3 can be evaluated and validated. Replicate annual surveys are essential for documenting changes in channel dimensions and can visualize changes in the channel. Thorough monitoring also allows for other models to be run and validated. For example, sediment transport models like GSSHA and FLOWSED can be used to make predictions and then calibrated or validated based on monitoring data collected in real time. This is significant because it improves the models used in the future for similar sites, and gives insight on how the stream behaved.

2.2 Stream Channel Habitats

As a stream forms riffles, runs, pools, and glides, it creates a variety of habitats for many diverse aquatic organisms. Figure 2.2 illustrates the progression between these features and the characteristics of each one. Each habitat supports different macroinvertebrates, which are crucial to fish populations in a stream.

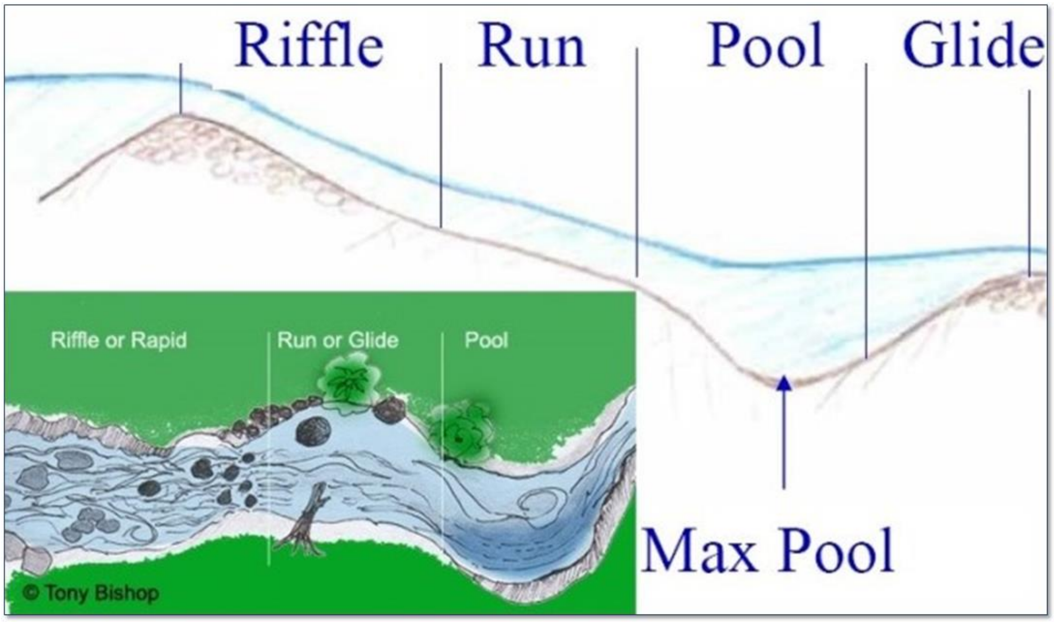

Figure 2.2. Visualization of bed feature patterns in a stream (Tony Bishop, 2018).

Riffles are characterized by shallow depths and fast moving, turbulent flows. These are typically found at cross-over locations and have a poorly defined thalweg (Bowden, 2004). The rockiness of riffles provides cover from predators, food deposition, and shelter (Cary Institute of Ecosystem Studies, 2012). Many invertebrate species reproduce and grow in riffles. There is also a high dissolved oxygen concentration in these areas due to the high turbulence.

Runs and glides are characterized by depths greater than riffles, smooth water surface, and moderate flows. These are typically found between riffles and pools, and have well defined thalwegs. Light penetrates easily since the water surface is smooth. These areas are preferred by smaller fish species.

Pools are characterized by greater depths and slow, uniform flows. These are typically found on the outside of bends, or behind debris such as large logs or boulders.

The water surface slopes of pools are near zero. The depths provide shelter from predators and protection from dry conditions.

The range of habitats provided by the various bed features are essential to maintaining a healthy stream ecosystem. The stability of the stream channel is directly related to the formation and support of these habitats.

Channel stability is an important factor in forming habitat in a stream, but is not commonly defined within physical habitat integrity. Information on geomorphic and hydraulic conditions of a channel are missing in current evaluations of biological and chemical impairments of habitat (Asmus et al., 2009). The morphology and hydrology of a stream channel combine to form the physical habitats within the channel. Factors like substrate types and sizes, riffle and pool dimensions, channel sinuosity, and flow patterns all influence biological communities (Lisle, 1979; Sullivan et al., 2006). Determining how these habitat elements are connected to stream stability will improve the understanding of how fluvial processes affect biological communities. Evaluating channel morphology is important not only for the physical aspects of stability and progression, but to the biological communities and habitat quality provided by the stream.

2.3. Channel Stability Evaluation

The following evaluations of channel stability are from Level 3 of Rosgen's stream classification method.

Rosgen's Bank Assessment for Non-point source Consequences of Sediment (BANCS) model has two parts. The Bank Erosion Hazard Index (BEHI) quantitatively assesses a stream bank's susceptibility to erosion. The BEHI requires measurements of the bank height and angle, vegetative rooting depth and density, percentage of vegetative surface protection, and type of bank materials. Near-Bank Stress (NBS) estimates shear stress on a bank and the risk of bank failure with a variety of methods involving ratios of various slopes or physical characteristics (Appendix A.5).

The BEHI model ratings range from 0 to 10, which correspond to “very low” through “extreme” in terms of risk of erosion (Appendix A.4). Ratios of the various measurements are converted into BEHI ratings using the provided conversions (Rosgen, 1996, 2001b, 2006b). The BEHI ratings are summed to find the total score, adjusting for bank materials and stratification. The BEHI model has been widely used in streambank evaluations, even finding success as an indicator for aquatic habitat health (Simpson et al., 2014). Other studies have criticized the model. Simon et al. (2007) stated that the BEHI works well as qualitative evaluation for communication, but that it does not account for the how or why a system is unstable. They advocate a mechanistic approach instead, concentrating on processes such as erosion, transport, and deposition.

Using these two parts together with regional curves, the BANCS model estimates annual erosion rates (Rosgen, 2013). Due to lack of measurements and applicable regional curves for the study area, only the BEHI values are used to represent potential erodibility in this study.

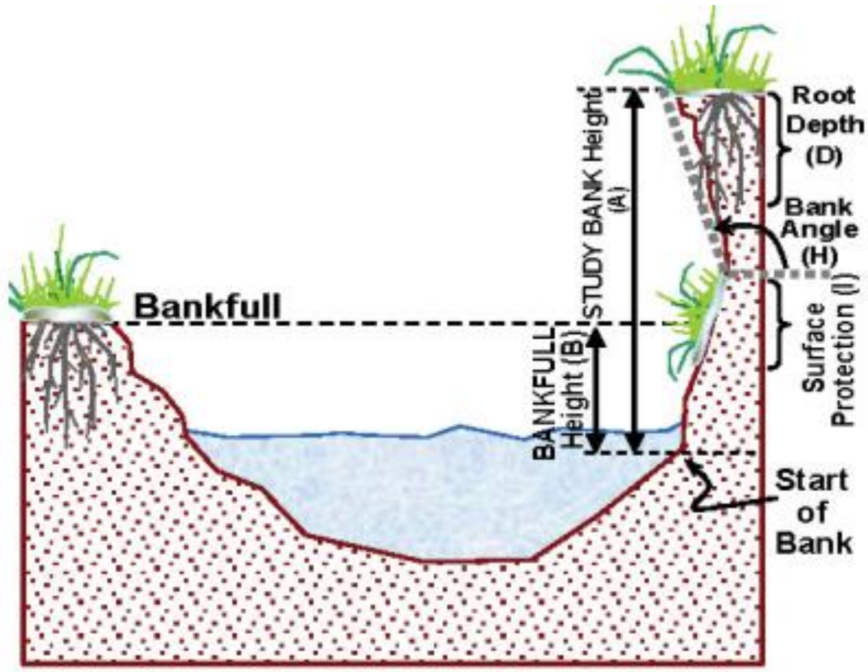

Figure 2.3. Measurements required for the BEHI Rating survey (Rosgen, 1996).

2.4. Grazing Management

Grazing on public land goes as far back as the 1860s, but it became a widespread practice in the 1920s as the cattle business became more popular (Tanner, 2015). It was highly profitable due to the lack of regulation on the use of public lands. An example of the tragedy of the commons, the open grasslands of the western United States became overcrowded and overgrazed. The Taylor Act of 1934 was enacted to regulate grazing of public lands (Maughan, 2014). Today, there are as many different grazing management strategies as there are ranchers. This study focuses on three general categories of grazing - conventional grazing, managed grazing, and grazing exclusion - and explores specific sites as examples of each. It is difficult to agree on universal definitions of grazing intensities as they vary based on climate, location, and personal preference (Trimble, 1995).

2.4.1. Conventional Grazing

Conventional grazing is defined as allowing the livestock to roam freely in the pasture without restricting the area or the time they spend there. While conventional grazing lowers management effort and infrastructure costs, and has been preferred by farmers due to its ease and economic benefits, there have been many studies showing the plethora of negative effects of this practice. Heavy grazing compacts the soil, which reduces infiltration and increases runoff (Platts, 1978; Trimble, 1995; Magner, 2008a; Tufekcioglu et al., 2012). This is especially the case where the cattle have formed paths or trails. Grazing cattle also impact the bank vegetation, creating more bare ground which increases erosion and sediment loads in the water (Platts, 1978; Trimble, 1995; Lyons, 2000; Moechnig, 2007; Grudzinski et al., 2016). Conventional grazing is second only to row crops in erosion and sediment production (Moore 1976; Zaimes 2004). Other direct impacts include collapsing banks under hoof shearing, water quality degradation from direct introduction of wastes, and overgrazing which can lead to degraded vegetative communities and overall pasture quality (Owens et al., 1989; Trimble, 1995; Sovell et al. 2000; Moechnig, 2007). Trimble 1995 concluded that light or moderate grazing would have much less significant effects. Tufekcioglu et al. 2012 observed that two metrics, the length of banks that were severely eroded and the soil compaction of riparian pastures, were positively related to stocking rates.

2.4.2. Grazing exclusion

The conventional solution to fixing impacted conventional grazing sites, livestock exclusion, is a simple but extreme strategy. Prohibiting all grazing has shown positive effects. Plant communities have been observed to flourish, especially woody vegetation, providing more cover and shade for the stream which is beneficial for aquatic species (Platts, 1978; Rickard and Cushing, 1982; Platts and Nelson, 1985; Freitas et al., 2014).

This can result in significant improvements without need for active restoration efforts (Batchelor et al., 2015). Excluding cattle from the riparian area has also been shown to significantly reduce suspended solids and nutrient concentrations in the stream (Owens et al., 1996; Line et al., 2000). In a 1970 study by Lusby, ungrazed watersheds produced only 71-76% as much sediment as grazed watersheds. Morphological effects included less entrenchment and wider stream banks in excluded areas than grazed areas (Platts, 1978; Kauffman and Kruger, 1984). On the other hand, some studies saw no significant morphological differences from grazing exclusion (Kondolf, 1993; Allen-Diaz et al., 1998; George et al., 2002).

Many of these exclusion studies have been criticized. Sarr (2002) observed three different post-exclusion dynamics. Systems may recover quickly and predictably as the studies have shown, but they may also "fail to recover due to changes in system structure or function," or recover slowly and remain more sensitive to livestock impacts because of the previous grazing. Also, the farmers incur additional costs of installing livestock exclusion fencing, routing a source of water, and providing hay or other feed for the herd.

2.4.3. Managed grazing

Careful management may be sufficient in mitigating the damage that cattle can cause. This can include grazing management strategies such as rotational grazing, seasonal grazing, short duration grazing, or implementing riparian buffers. All of these strategies limit the time or the area that the cattle are allowed to graze. There are as many grazing management strategies as there are farmers, making it difficult to group or compare them. However, comparing managed strategies to conventional grazing or grazing exclusion has been done in numerous studies. The recovery of vegetative communities in managed grazing sites has been observed to be very similar to those in grazing excluded sites (Freitas et al., 2014). Various managed grazing strategies were also seen to be effective options for reducing soil erosion and runoff (Magner, 2008b; Pilon et al., 2017). Managed sites had less bank erosion and suspended sediments than conventional sites in a watershed in southwestern Wisconsin (Lyons, 2000b). Managing grazing systems properly is an efficient and effective method for rehabilitation of the stream resources (Kauffman and Kruger, 1984).

Like grazing exclusion, managed grazing has additional economical costs over conventional grazing. More attention is required from the landowner to move the cattle in rotational or short duration grazing systems (Peppler and Fitzpatrick, 2004). Additional fencing, feed, and water source costs may also be required (Platts and Wagstaff, 2011). Adding buffers will reduce the area of pasture available and may only support smaller herd sizes. However, a study by Undersander et al. in 2002 should be considered, which found that rotational grazing can increase forage production over conventional management. Additionally, cost-share programs exist for water pumps and fencing expenses. Caring for the stream system is vital to the quality of the land around it, and for everything downstream. Unmanaged upstream riparian areas can exert significant sediment and water quality impacts downstream (Platts and Nelson, 1985). Through cost-share programs and future benefits of a recovered riparian pasture, proper management of riparian ecosystems can easily be profitable for landowners (Marcuson, 1977).

2.4.4. Grassed and Wooded Banks

Managed grazing tends to favor grassed banks, as the grazing provides natural management of the vegetation. Woody species like shrubs and especially trees will have trouble establishing and growing to heights where they can survive the grazing. Smaller grasses and forbs will have an easier time growing and spreading (Blanchet, 2000).

While wooded managed grazing sites exist, they are more commonly seen in grazing exclusion sites (Rickard and Cushing, 1982). Riparian vegetation is important for bank protection, stabilization, and erosion prevention. Riparian vegetation has been shown to result in narrower channels by trapping sediment and preventing bank erosion (Kondolf, 1993; Magilligan and McDowell, 1997). Overall, wooded banks are perceived to be less effective at sediment retention. Percentages of fine sediments in the stream and rates of bank erosion are significantly higher in wooded buffers than grassed areas (Lyons et al., 2000a; Sovell et al., 2000). Also, grassed banks tend to have denser root systems, which better stabilize the bank. Wooded areas tend to have more exposed soil and larger yet less dense roots. Grassed riparian areas are may be more effective in agricultural regions, reducing bank erosion and trapping suspended sediments (Lyons et al., 2000b). A study by Simon and Collison in 2002 quantified the stability benefits of roots. Grass roots contributed two to three times as much soil strength as tree roots. However, this is significantly affected by other factors such as the mechanical effects of shade from tree cover or hydrologic effects from flooding or storm events. It is important to consider the hydrologic as well as mechanical and ecological criteria when selecting riparian vegetation (Simon and Collison, 2002).

3. METHODS

3.1. Study Sites

Nine sites on four reaches of three different streams were included in this study: the 600th Ave reach of Dobbins Creek, the reference reach of Dobbins Creek, the T-7 reach of Sugarloaf Creek, and the 300th Ave reach of Elm Creek. The inclusion of a reference reach was recommended by the DNR to provide a guideline for comparison. A study site was generally defined to be 30-40 stream channel bankfull widths long and consisting of one of three riparian grazing management strategies: grazing exclusion or non-grazing (NG), managed grazing (MG), or conventional grazing (CG). Silt loam or clay loam soils were dominant at all of the study sites. Percent slopes varied from 0 to 6 percent. The land uses for the study sites were mainly cultivated crops, apart from a few forested areas (Stream Stats, 2018).

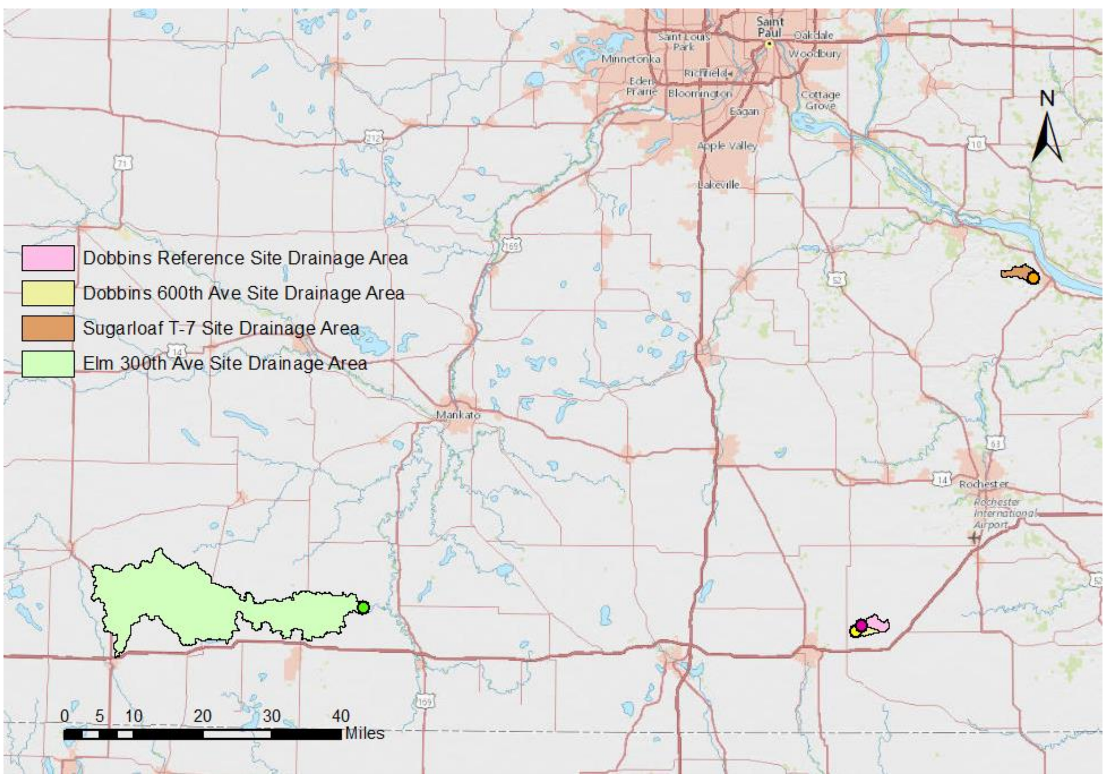

Figure 3.1. The four study sites and their drainage areas in relation to each other.

3.1.1. Dobbins Creek

The 600th Ave reach is split into three sites; the northern and middle reaches are CG while the southern reach is NG and wooded. Historically, the landowner has used the riparian area as pasture for 12 to 14 calf-cow pairs of Angus beef cattle. For the past 20 years, the grazing management strategy has been to openly graze the cattle in the riparian area during the warm seasons, generally May or June until September or October. The northern reach hosts cattle for all of these months, while the middle reach is usually grazed one or two months less than the northern reach, depending on the severity of the grazing and the condition of the pasture there (Photos J.1.2, J.1.3, and J.1.8). The southern reach is a wooded corridor between two fields, with steeper slopes and larger boulders that were artificially introduced (Photos J.1.11 and J.1.12). Due to these conditions, grazing has never occurred in this section. Measurements were made for the 600th Ave reach during the summers of 2016 and 2017. Data was collected to compare the reaches and assess the condition of the stream bed and banks.

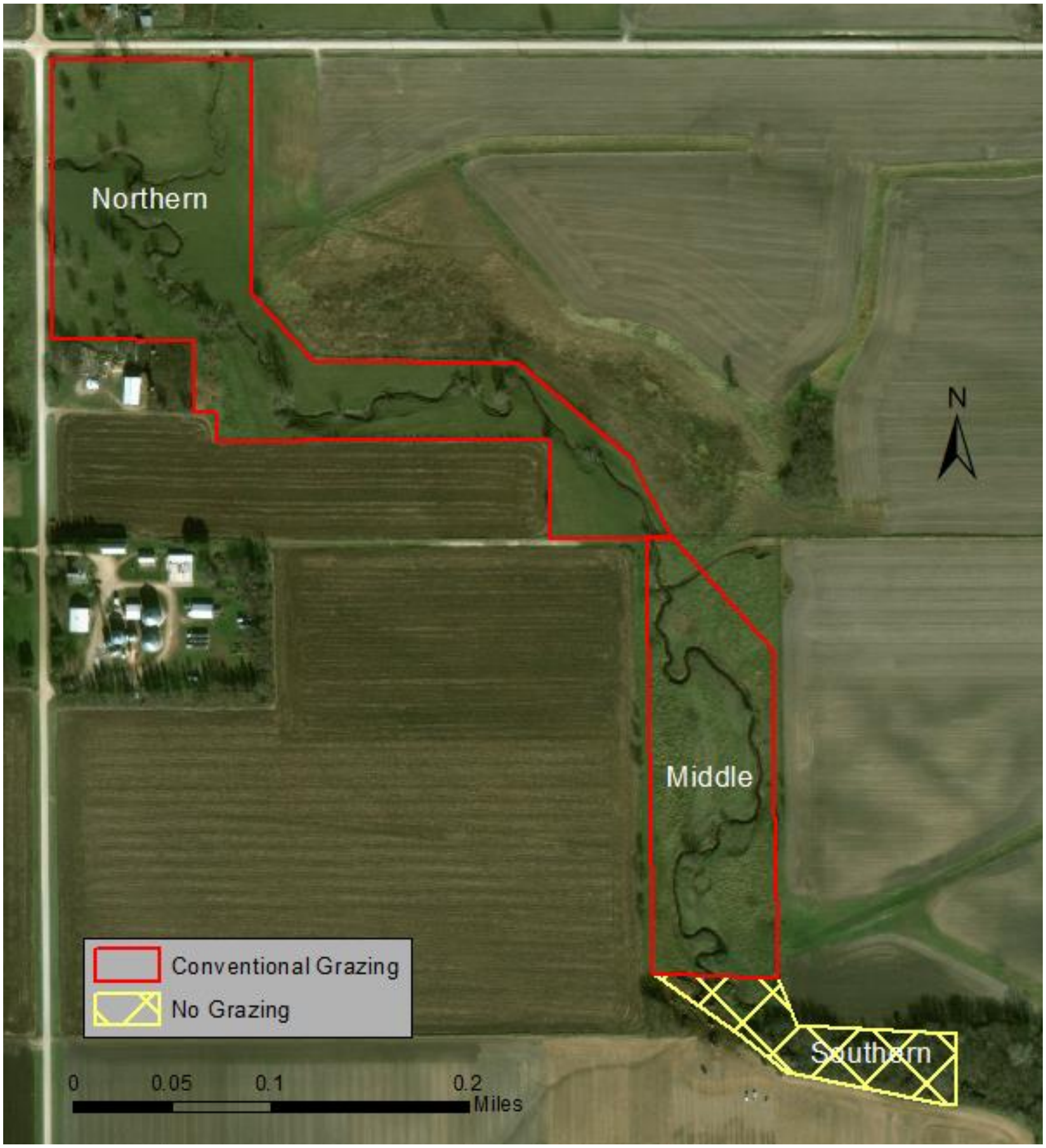

Figure 3.2. 600th Ave reach of Dobbins Creek.

The reference reach is further northeast and upstream of the 600th Ave reach. This has historically been non-grazed. It was surveyed by the DNR in May of 2017 and was used as the best available reference reach for stream projects in the region. Geomorphological survey data was available in RIVERMorph.

Figure 3.3. Reference reach of Dobbins Creek.

3.1.2. Sugarloaf Creek

The T-7 reach landowner conducted a study by managing four different sections of pasture differently. Unlike the 600th Ave reach, grazing was much more restricted. This site had 155 acres for grazing 40 non-dairy Pinzgauer cow-calf pairs. Grazing strategies were changed from CG to MG at site A and B (Photo J.2.2, J.2.3, J.2.4, and J.2.5). Site A allows grazing for three days every two months while site B was stricter and allowed grazing for only three days per year. Site C is wooded and has been NG since 1967 (Photo J.2.6 and J.2.7). In 2005, part of that area was cleared of trees and turned into Site D, being grazed three days every two months, like site A (Photo J.2.8 and J.2.9). The T-7 reach was surveyed in 2005 and 2010 (Cristina Lopez-Barrios, 2011). The data is compared by year and site to show the difference these changes have had on the area.

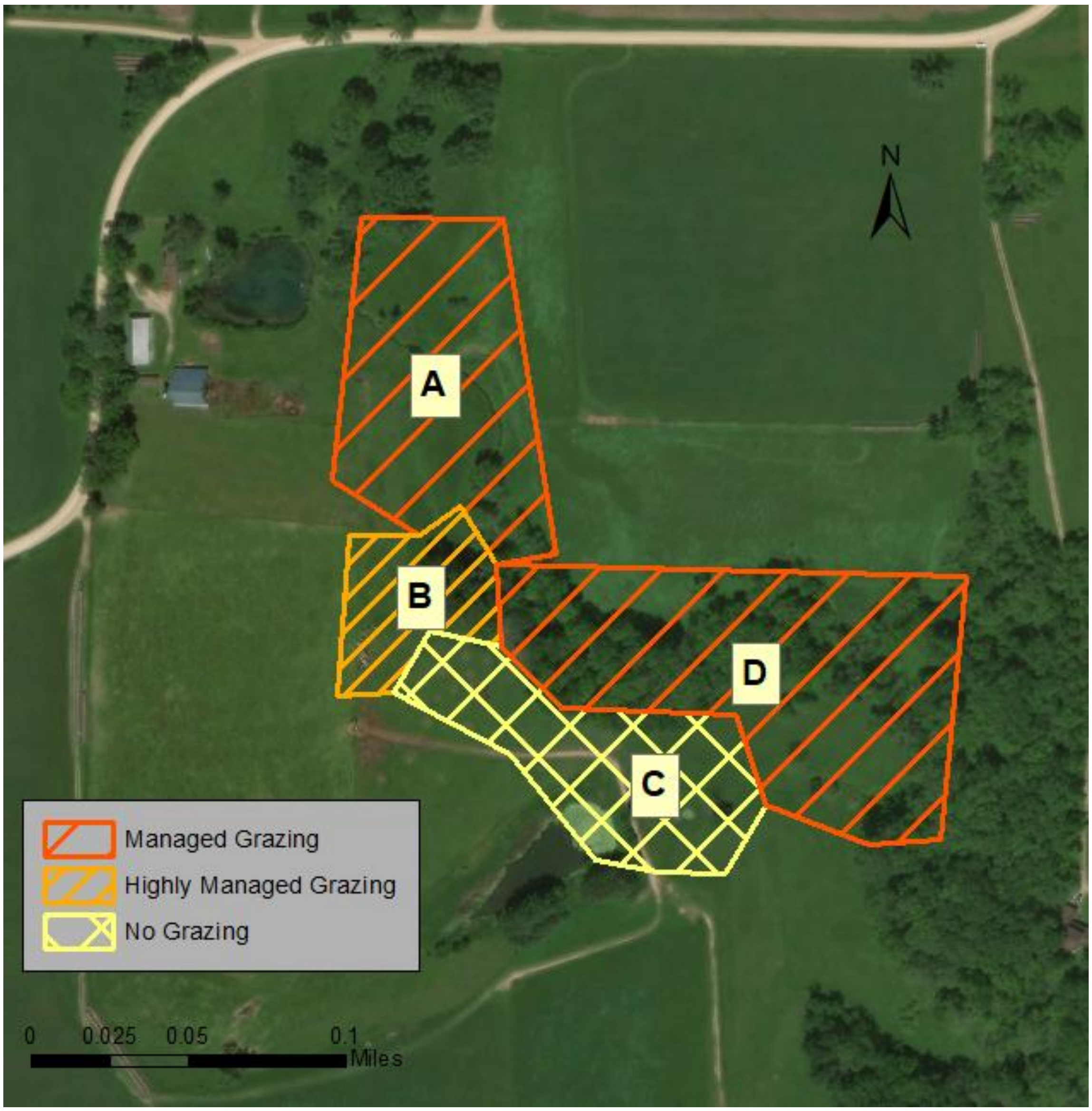

Figure 3.4. T-7 reach of Sugarloaf Creek.

3.1.3. Elm Creek

The 300th Ave reach site on Elm Creek underwent a large-scale restoration in 2007. In the area for phase 1, the banks were revegetated and reshaped to improve stability, and the cattle crossing area was stabilized (Photos J.3.2, J.3.3, and J.3.4). In phase 2, the oxbow was reconnected to reduce flows and the banks were revegetated and reshaped here as well (Photos J.3.5, J.3.6, J.3.7, J.3.8, J.3.9, and J.3.10). In phase 3, six log vanes were placed to reduce the stress on the outer bank (Photos J.3.11, J.3.12, J.3.13, J.3.14, J.3.15, J.3.16, and J.3.17). Again, bank revegetation and reshaping was used to improve stability. The reaches restored for phases 1 and 2 belong to a different landowner than the phase 3 reach. Following the completion of this project, the two landowners resumed their practices. Phase 3 returned to being NG while phases 1 and 2 returned to CG of Hereford and Angus cattle. The oxbow on the west bank of phase 2 that was reconnected was fenced off until 2012, but the rest of phases 1 and 2 were open for the cattle to roam freely. The 300th Ave reach was surveyed in 2006 and 2009, by Dr. Chris Lenhart. This site allows for direct comparison of grazing and non-grazing impacts at a site that has recently been restored.

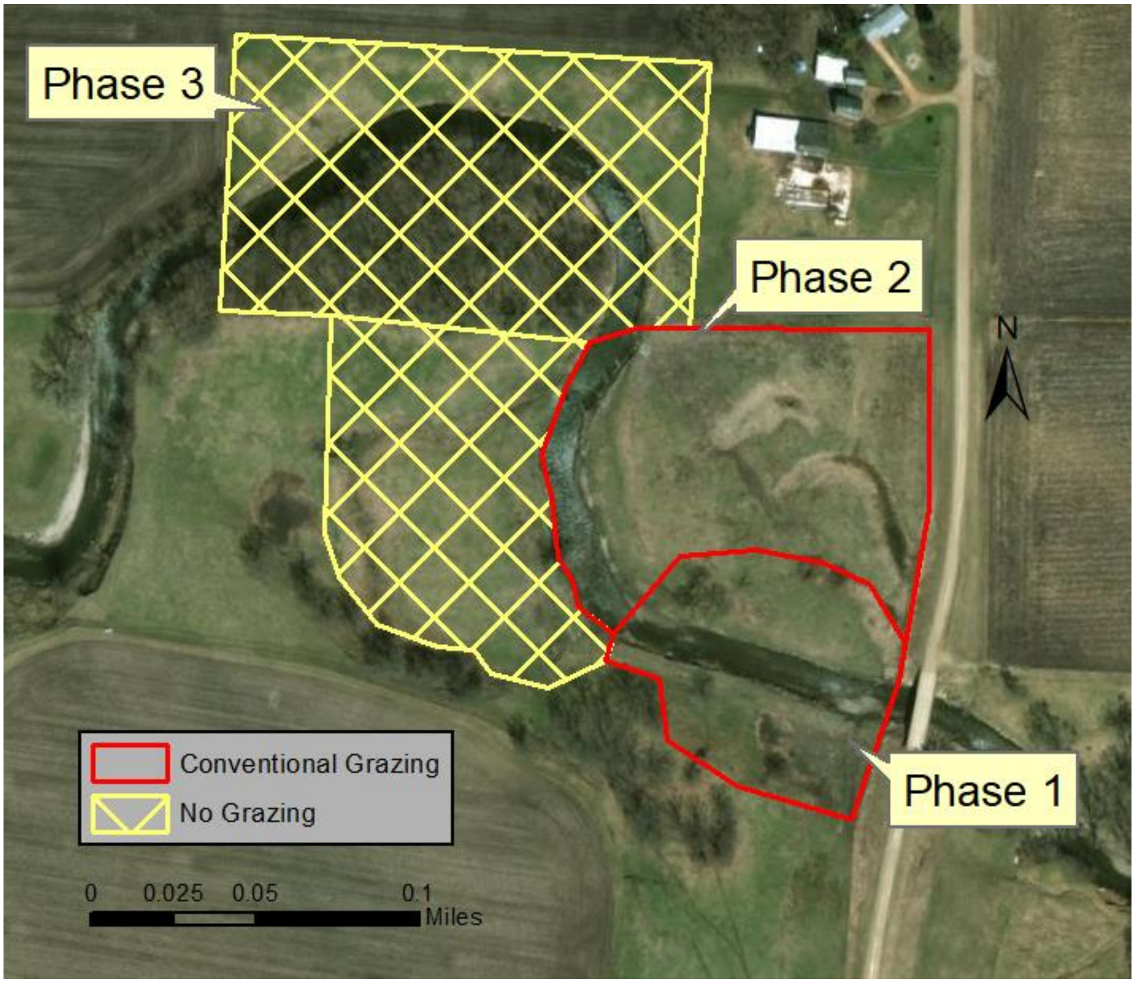

Figure 3.5. 300th Ave reach of Elm Creek.

3.2. Geomorphological Surveys

For each creek, a longitudinal profile was surveyed (Appendix A.1). At least one cross-section was conducted in order to gather morphological data and classify the reach using the Rosgen classification method (Appendix A.2). A pebble count survey was conducted at each reach as well, to obtain particle size distributions for the sites (Appendix A.3). Channel and bank stability were evaluated using the BEHI method (Appendix A.4). Other characteristics were evaluated using spatial maps. Geospatial maps were used to determine additional parameters. Flood-prone areas were measured on topographic maps at twice the depth of the channel at bankfull conditions. The channel length was previously measured through the longitudinal profile and was divided by the valley length, measured using aerial images, to calculate sinuosity. Radius of curvature, meander wavelength, and belt width are also determined using aerial imagery.

The morphological data for the 600th Ave reach were entered into the RIVERMorph application (Appendix C). For all other reaches, data were already available in Mecklenburg Excel sheets, which serve a similar function as the RIVERMorph application (Mecklenburg, 2011). Resources like RIVERMorph or Mecklenburg sheets are used to calculate the bankfull width, bankfull area, mean depth, maximum depth, width-depth ratio, entrenchment ratio, and channel slope by using the inputs of the longitudinal profile and cross-section surveys (Belcher and Athanasakes, 2002; Mecklenburg and Ward, 2011). They also provide automated ways of visualizing the data. Longitudinal profiles and cross-sections can be plotted and edited. The particle size distribution is also plotted from the pebble count input, providing mean particle sizes and percentages of silt-clay, sand, gravel, and cobble. A benchmark elevation was noted in the field to later adjust the elevation measurements to be relative to a single true elevation at the site. Some of the data had to be remeasured or recalculated due to extreme measurement or human errors. For example, the flood prone area widths for Sugarloaf Creek were reported to be around 30 ft in the Mecklenberg sheet, but remeasuring this dimension on aerial and topographic maps, it was found to be around 400 ft.

3.3. Data Analysis

The main tools used for the statistical analysis were Microsoft Excel and R. The data were analyzed, both separately by site, and as one dataset for the overall analysis.

3.3.1. Correlation

First, a correlation matrix was generated between all of the variables measured. Table 4.1 shows how strongly each variable is associated with another, indicated by the p-values. For example, bankfull width and the width-depth ratio are expected to be highly correlated. This table supports expected correlations and exposes unexpected ones. This is useful for filtering the variables for exploratory data analysis, such as developing proper regression models.

3.3.2. Standardization

For the overall dataset, the data points were standardized. Standardizing multivariate data is important to account for significant differences in variable scales. It can also help reduce multicollinearity issues when running regression models. The standardized overall dataset is shown as Table B.2 in Appendix B.

3.3.3. Analysis of Variance

One-way analysis of variance, or ANOVA, was used to determine whether there are any statistically significant differences between the means of three or more independent groups. An alpha level of 0.05 was used as criterion for reporting statistical significance. Post-hoc tests are used to find where the differences occurred between groups, and they are only run when the ANOVA showed an overall statistically significant difference in the group means. The post-hoc test I applied is the Games-Howell test (Equation 3.7 and Equation 3.8). This is needed because the groups and their variances are uneven. Two groups within the ANOVA are compared. The modified version of Tukey's honest significant difference test uses this denominator, shown in Equation 3.7, to account for uneven group sizes and unequal variances. Error in degrees of freedom should also be adjusted if this modification is used, and the final q value obtained from the Games-Howell test is compared against a critical value obtained from studentized range q tables. Depending on the error in degrees of freedom and the number of groups used in the ANOVA, the critical value will vary. If the q value is greater than the critical value, that comparison is significantly different. An example of this post-hoc test is given below.

Equation 3.6. Tukey's formula that is modified.

formula:

$$\frac{M_1 - M_2}{\sqrt{MS_w\left(\frac{1}{n}\right)}}$$

M = treatment/group mean
n = number per treatment/group

Equation 3.7. Games-Howell modification made to the bottom term in Tukey's formula.

$$\sqrt{\frac{\frac{s_i^2}{n_i} + \frac{s_j^2}{n_j}}{2}}$$

Equation 3.8. Games-Howell degrees of freedom modification.

$$df' = \frac{\left(\frac{s_i^2}{n_i} + \frac{s_j^2}{n_j}\right)^2}{\frac{\left(\frac{s_i^2}{n_i}\right)^2}{n_i - 1} + \frac{\left(\frac{s_j^2}{n_j}\right)^2}{n_j - 1}}$$

3.3.4. Regression Models

The purpose of regression analysis is to predict the value of one dependent variable from the values of independent variables. In order to determine what combination of independent variables best represents the dependent variable, backward stepwise selection was used. This model starts with all of the variables, then removes the least useful predictor. It repeats this process until all predictors are significant. This provides a starting point, and then variables were added or removed based on their p-values. The best combination is generally determined by the lowest p-values and highest adjusted R-squared value. The adjusted R-squared value is the fraction by which the variance of the errors is less than the variance of the dependent variable, adjusted for the number of coefficients in the model relative to the sample size. However, since the goal is to determine which predictors are statistically significant and how changes in these predictors influence changes in the response variable, the R-squared value is not as important. The dependent variable, predicted dependent variable, and 95% confidence intervals are then plotted to view the prediction.

4. RESULTS

There are no clear criteria for determining which variables best distinguish stream channels. This study hopes to better inform future studies by finding differences in variables between sites. One-way ANOVA tests found significant differences in certain variables between grazing types overall as well as between the Dobbins reaches. The post-hoc Games-Howell test provided further insight into the differences between the groups. A correlation table and regression models were used to determine what relationships exist between the variables.

4.1. Correlation

Expected correlations were confirmed between variables that increase with drainage area, or size and volume. These include measurements such as bankfull width and bankfull area. Correlations were also expected between any dimensions and any ratios or calculations including those parameter, such as bankfull area and hydraulic radius. Some correlations worth noting are the particle sizes with drainage area and bankfull area.

Table 4.1. Correlation matrix showing the relationships between the measured and calculated dimensions.

	Drain Area	BKF Width	BKF Depth	Max Depth	BKF Area	W/D Ratio	FPA Width	Entr. Ratio	Hyd. Rad.	WS Slope	Valley Length	Channel Length	Sinuosity	Reach D50	Reach D84	Riffle D50	Riffle D84	BEHI Score
Drain Area	1.000																	
BKF Width	0.894	1.000																
BKF Depth	0.662	0.403	1.000															
Max Depth	0.469	0.473	0.633	1.000														
BKF Area	0.962	0.874	0.766	0.576	1.000													
W/D Ratio	0.486	0.744	-0.151	-0.008	0.443	1.000												
FPA Width	0.793	0.899	0.270	0.487	0.719	0.621	1.000											
Entr. Ratio	0.215	0.309	-0.140	0.247	0.101	0.192	0.676	1.000										
Hyd. Rad.	0.753	0.559	0.968	0.640	0.856	0.044	0.394	-0.107	1.000									
WS Slope	-0.189	0.095	-0.526	-0.129	-0.266	0.259	0.283	0.456	-0.483	1.000								
Valley Length	-0.110	-0.137	-0.234	-0.022	-0.167	-0.209	-0.062	0.158	-0.252	-0.204	1.000							
Channel Length	-0.176	-0.365	-0.064	-0.135	-0.207	-0.447	-0.359	-0.116	-0.163	-0.340	0.590	1.000						
Sinuosity	-0.199	-0.373	0.171	-0.063	-0.157	-0.398	-0.420	-0.350	0.066	-0.326	-0.339	0.470	1.000					
Reach D50	0.542	0.527	0.336	0.132	0.563	0.297	0.354	0.024	0.400	-0.091	-0.103	0.119	0.016	1.000				
Reach D84	0.207	0.329	-0.102	-0.321	0.186	0.454	0.179	-0.092	-0.017	0.413	-0.338	-0.261	-0.128	0.428	1.000			
Riffle D50	-0.134	-0.279	-0.271	-0.331	-0.232	-0.261	-0.284	0.104	-0.355	0.779	0.628	0.834	0.068	0.067	0.188	1.000		
Riffle D84	0.886	0.728	0.425	0.160	0.819	0.356	0.719	0.202	0.488	0.478	0.001	0.303	-0.023	0.934	0.927	0.334	1.000	
BEHI Score	-0.288	-0.305	0.111	0.158	-0.163	-0.406	-0.262	-0.041	0.084	-0.102	-0.073	0.064	0.146	0.069	-0.346	0.100	-0.002	1.000

0.8 to 1.0	High correlation
0.5 to 0.8	Moderate correlation
0.4 to 0.5	Slight correlation
0.0 to 0.4	Weak correlation

4.2. Dobbins Creek: 600th Ave and Reference

Two properties along Dobbins Creek are included in this study; the 600th Ave site and the reference site (Figures 3.2 and 3.3). The 600th Ave site is split into three sections; the northern and middle sections are CG while the southern section is wooded and NG (Appendix J.1). While the middle section is generally grazed about one month less than the northern section each year, no significant disparity was found between the two CG sections. The CG areas were observed to have little vegetative cover and low vegetative diversity, with most of the area being populated by sedges and nettles (Photos J.1.7 and J.1.8). Many of the banks were bare and the channel bed consisted mostly of silt and sand (Photos J.1.5 and J.1.6). At several spots along the sections, the banks had collapsed due to livestock crossing the stream and many other areas were observed to be trampled and the soil compacted (Photo J.1.4).

Significant differences in water surface slope, particle sizes, and BEHI ratings were found from the ANOVA tests (Tables E.1 to E.8). The post-hoc Games-Howell tests revealed that the most significant differences were between the northern and reference, and middle and reference reaches (Tables E.5.1, E.6.1, E.7.1, and E.8.1). The CG sections were found to be significantly different from the grassed NG section. The grassed NG section had larger reach D50 and D84 than the two CG sections (Figures 4.2 and 4.3). Also, the slopes were significantly flatter at the CG sections (Figure 4.4). Finally, while BEHI ratings varied between all sections, the most significant difference was in fact found between the northern and middle reaches (Figure 4.5). The northern reach had the highest ratings while the middle and southern reaches were lower. Unfortunately, the reference reach did not have any BEHI data available.

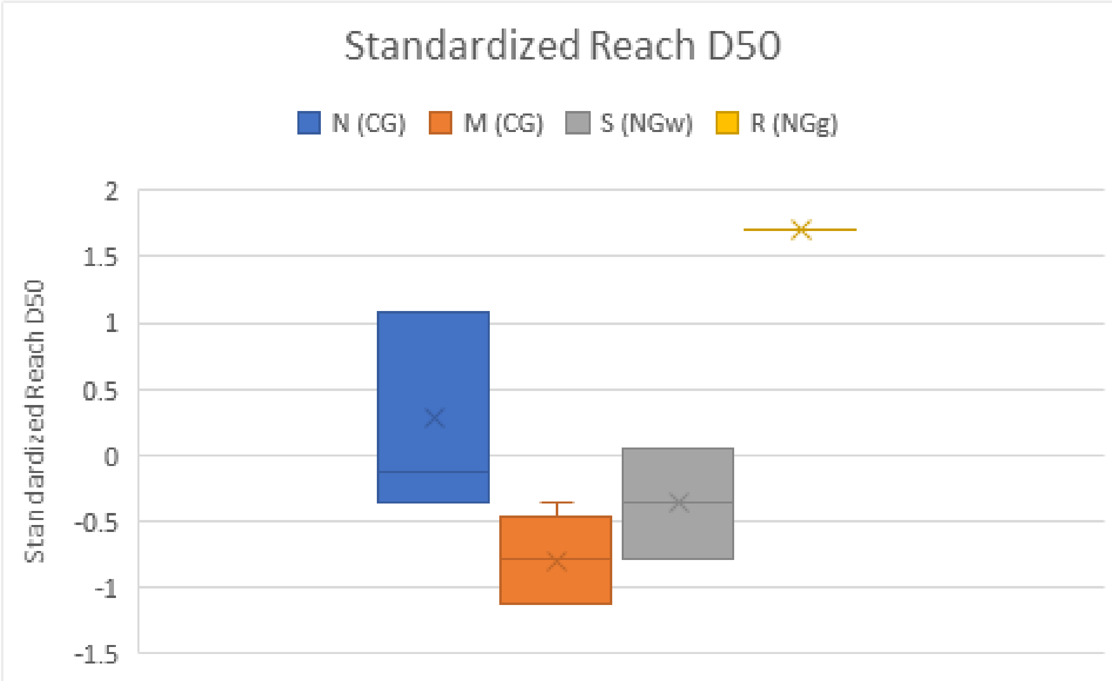

Figure 4.2. Statistically significant differences in Reach D50 of Dobbins creek sites.

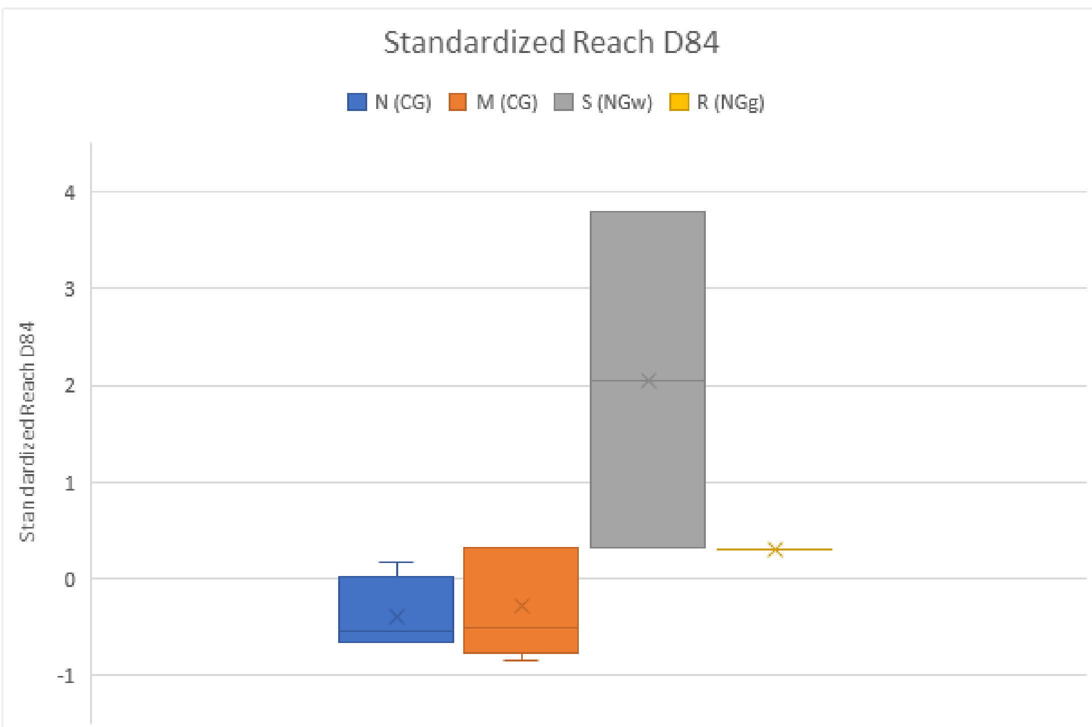

Figure 4.3. Statistically significant differences in Reach D84 of Dobbins creek sites.

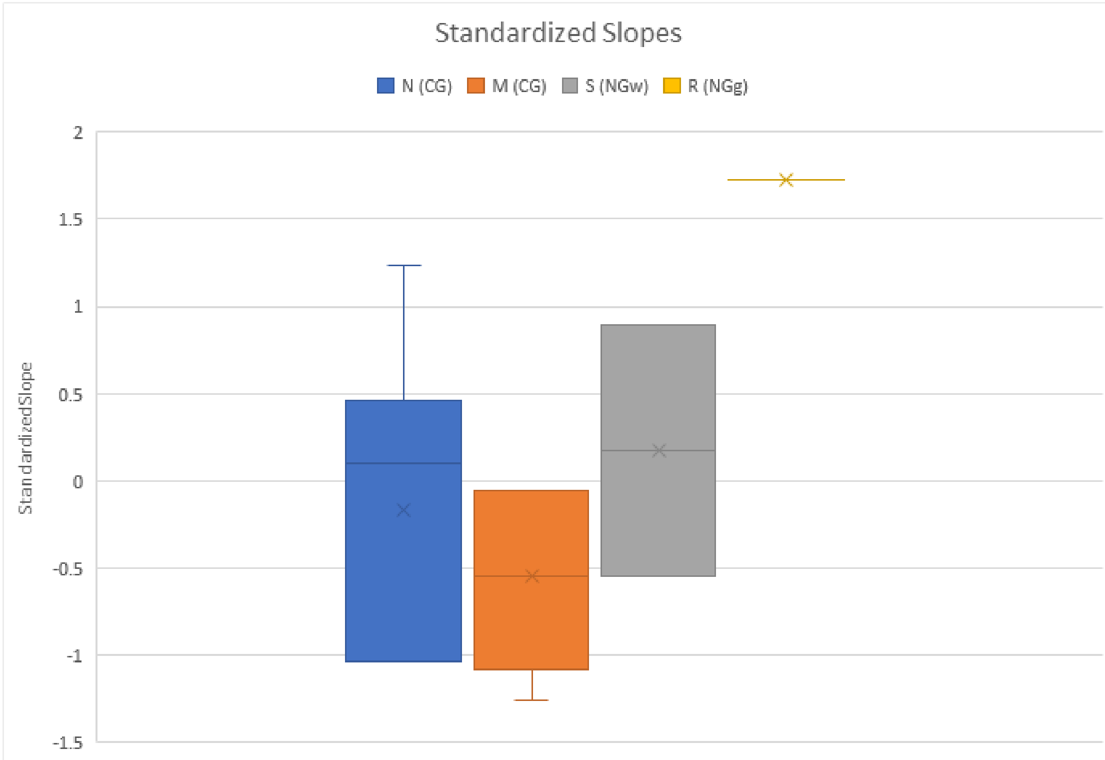

Figure 4.4. Statistically significant differences in slope of Dobbins creek sites.

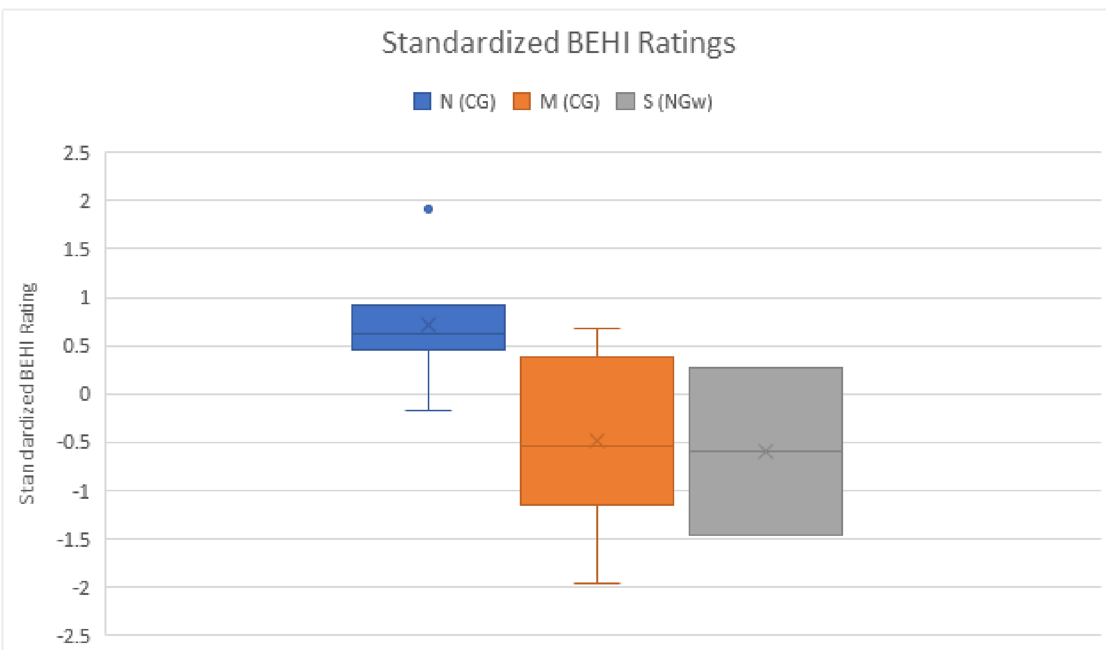

Figure 4.5. Statistically significant differences in BEHI rating of Dobbins creek sites.

On average, the CG sections had wider and deeper channels, but were less entrenched (Tables E.1, E.2, E.3, and E.4). Compared to the grassed NG reference reach further upstream, the 600th Ave sites had larger widths but similar depths, resulting in much larger bankfull areas and width-depth ratios. The reference reach had less entrenchment despite having less floodplain area due to the smaller size of the stream. Larger reach and riffle particle sizes indicates that the reference site had better defined bed features and less fine sediments.

4.3. Sugarloaf Creek: T-7

The T-7 site includes three MG sites and one NG site. These are denoted by the letters A, B, C, and D (Figure 3.4). Changes were made to the grazing management strategy in 2005. Site A was changed from CG to being grazed for three days every two months (Photos J.2.2 and J.2.3). B was switched from CG to only being grazed three days every year (Photos J.2.4 and J.2.5). Section C has been kept as NG since 1967, while D was changed from NG to being grazed three days every two months (Photos J.2.6 to J.2.9). Since these management changes, site A was observed to have a reduction in fine sediments and an increased particle size distribution. Site B had a reduction in fine sediments and an increased particle size distribution. Larger changes were observed at site C, where the channel widened to a B channel and created a new floodplain within the old G channel. This decreased the entrenchment ratio. Particle sizes drastically decreased as well (Figure 4.6 and Figure 4.7). Site D saw reduced bank slopes and the change from an E to a B channel. Like C, the particle sizes here saw a large decrease, but site D was the only site to see an increase in the depth of fines (Figure 4.8).

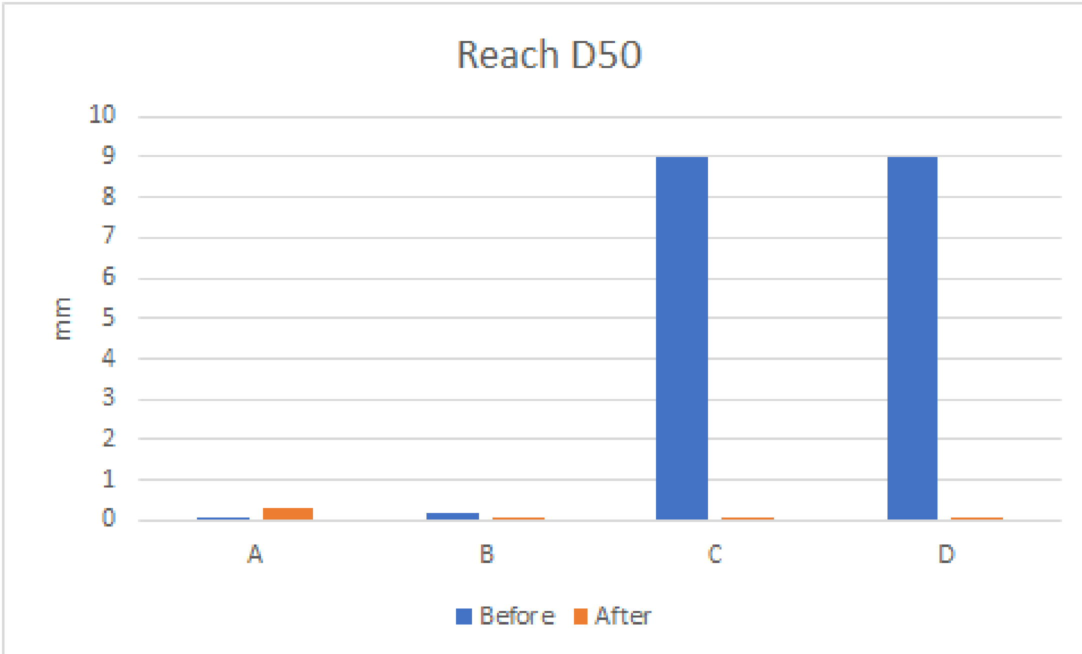

Figure 4.6. Comparing Reach D50 between sites, before and after restoration.

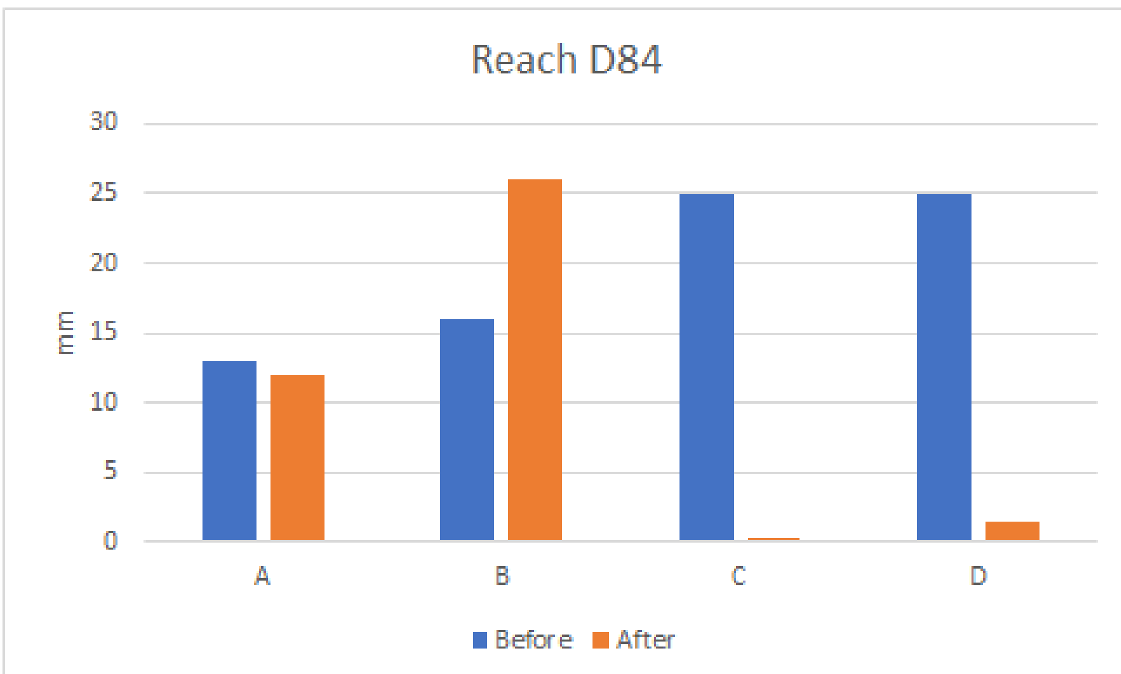

Figure 4.7. Comparing Reach D84 between sites, before and after restoration.

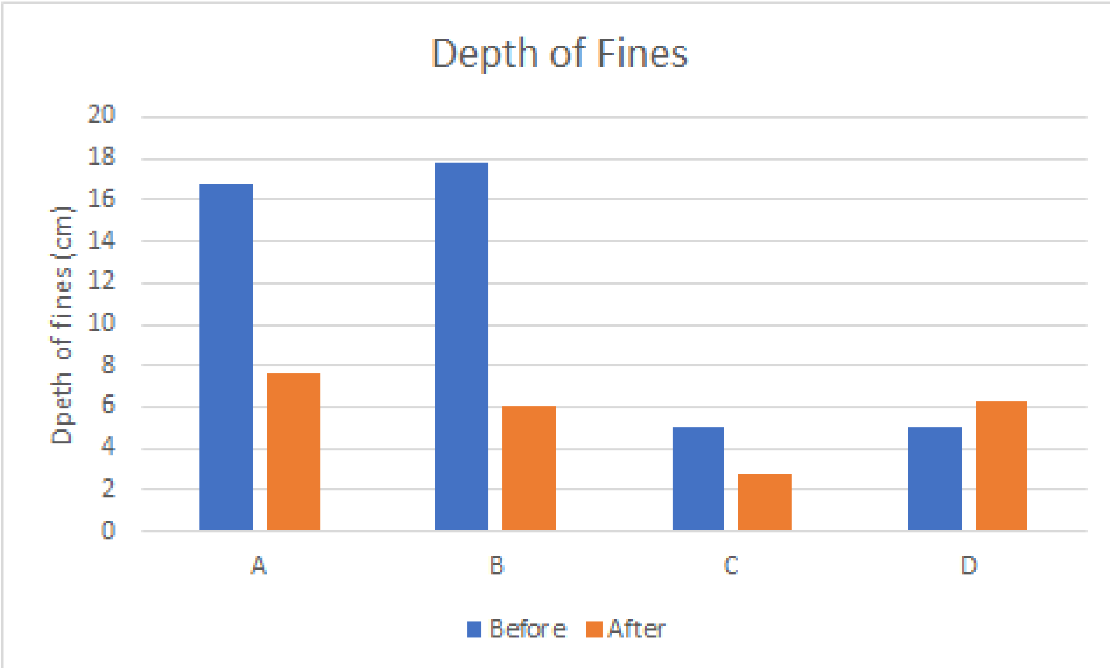

Figure 4.8. Comparing depth of fines between sites, before and after restoration (Cristina Lopez-Barrios, 2011).

After the management changes, A and B had higher entrenchment ratios than C and D. The pool depths were largest at sites A, then C. Pool lengths were especially high at site A (Table F.12). C and D had the higher BEHI ratings of 41 and 35, while A and B had lower ratings of 24 and 28, respectively (Table F.13). Sites C and D were highly and very highly at risk of erosion, while A and B were in the moderate category. Vegetative cover data was available from this study. As shown in Table 4.9 below, sites A and B had much lower percentages of bare cover than sites C and D. The percentage of grass and herbaceous cover are especially low in site C. However, site C had the highest percentage of tree cover. Overall, the areas that were changed to be MG saw higher percentages of vegetative cover, greater bank stability, lower risk of erosion, narrower channels, larger pools, and larger particle sizes.

Table 4.9. Relative cover compositions at Sugarloaf sites after management changes (Cristina Lopez-Barrios, 2011).

Section	Tree %	Bush %	Grass %	Herb %	Bare %
A (MG)	3.08	7.24	18.68	56.65	14.24
B (MG)	4.15	2.67	23.74	59.64	9.80
C (NG)	5.25	1.10	4.01	26.43	63.21
D (MG)	3.00	4.18	12.73	50.69	29.40

4.4. Elm Creek: 300th Ave

While the 300th Ave sites belong to different landowners, geomorphologically they are very similar. This section of Elm Creek, much like the rest of the Elm Creek Basin, suffered from channel erosion. High suspended sediment loads were caused by a lack of land cover, intensive land use practices, extensive tile drainage systems, channel straightening, and livestock grazing (Grudzinski et al., 2016). In order to reduce channel erosion and reduce the sediment load, a restoration project was implemented to increase vegetation and stabilize the banks. In phase 1, the banks were severely eroded and lacking vegetative cover (Photo J.3.2). The restoration included revegetation of the banks, reshaping the banks, and reinforcing the cattle crossing. For phase 2, the main problems were an eroded cattle crossing and lack of riparian buffer vegetation (Photos J.3.5 and J.3.6). This caused the stream to widen and become entrenched. The restoration project reconnected an old oxbow to reduce the flow velocity, reshaped and stabilized the bank using erosion control fabric, and revegetated the bank, mainly with sandbar willows. For phase 3, tree vanes were placed to reduce the energy of the flow into the stream bank. Similarly to phase 2, this bank was stabilized and revegetated (Photos J.3.11 to J.3.17). While photos immediately following the restoration look great, the return of livestock to phase 2 has undone many of the positive effects of the project.

A site visit at the end of February of 2018 provided key observations. While phase 3 retained good vegetative cover and had many sandbar willows on the banks, no willows were seen in phase 2, as much of the vegetation had been destroyed before it had a chance to establish. For phase 2, the cross vane that is supposed to redirect the flow to the oxbow is suffering from aggradation. Sand is building up at the entrance and along the oxbow channel, reducing the amount of water entering. Eventually, this will become disconnected from floodplain flows again.

The main differences shown by the data is in the width-depth and entrenchment ratios. All other factors remained constant despite the restoration project and the grazing. Phase 2 saw the greatest increase in width-depth ratio, likely due to the widening channel after the sediment bar was moved as well as the continued erosion of the banks from the grazing. Phases 1 and 2 became more entrenched, while phase 3 remained in nearly the same state.

Table 4.10. Data of pre-restoration conditions and the three restored phases.

Section	Bankfull Width (ft)	Bankfull Depth (ft)	Width-depth Ratio	Entrenchment Ratio
Pre-restoration (2006)	65.60	4.47	14.70	7.62
Phase 1 (2009)	57.70	3.92	15.60	4.85
Phase 2 (2009)	70.60	3.53	20.01	5.84
Phase 3 (2009)	60.51	3.69	16.68	7.26

It is difficult to compare the other sites to the Elm Creek sites due to the difference in drainage areas of the streams. Elm Creek has a drainage area of 272 square miles while Dobbins and Sugarloaf Creek are both under 10 square miles. However, the results of allowing CG on a newly restored riparian area can apply to all streams, regardless of size. For the overall data analysis, the standardization process mitigates the effects of the difference in drainage area.

4.5. All sites

NG sites include the reference reach, the southern part of the 600th Ave reach, site C of the T-7 reach, and phase 3 of the 300th Ave reach. MG sites include sites A, B, and D of T-7 reach. CG sites include the northern and middle sections of 600th Ave reach, as well as the phase 2 section of 300th Ave reach. Between CG, MG, and NG overall, statistically significant differences were found in entrenchment ratios and slope (Tables D.4 and D.5). Between CG and MG, the difference in entrenchment ratios was statistically significant. CG sites were the most entrenched, while MG sites were the least entrenched (Figure 4.11). For slope, MG had the steepest slopes while CG had the flattest slopes (Figure 4.12).

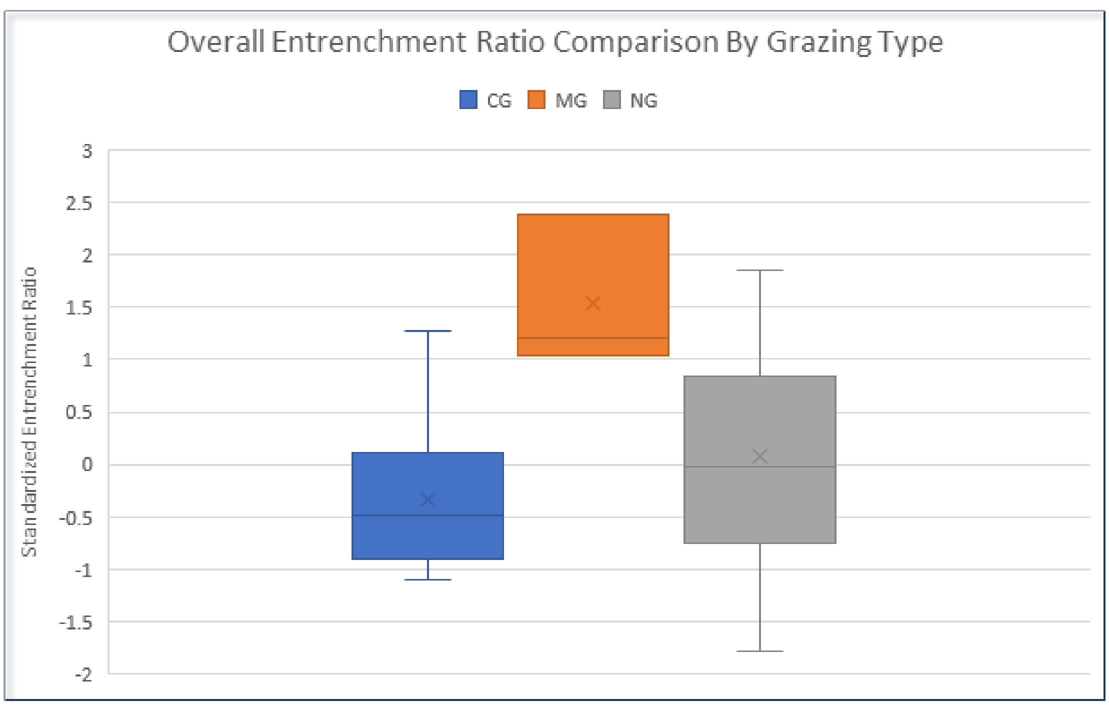

Figure 4.11. Entrenchment ratio by grazing type for the overall standardized dataset.

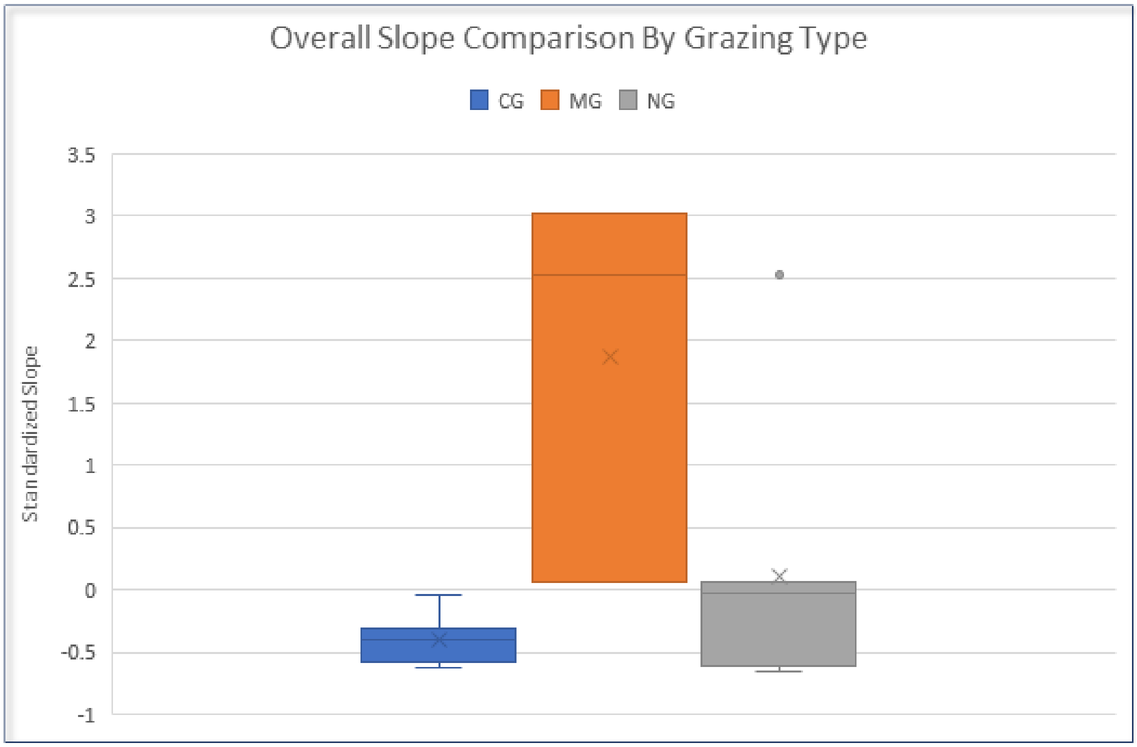

Figure 4.12. Slope by grazing type for the overall standardized dataset.

While not statistically significant, there are other differences that are still noteworthy. CG sites had the highest BEHI rating, or risk of erosion, while MG sites had the lowest ratings. The width-depth ratio was smallest at NG but largest in MG. MG channels had the largest D84 particle sizes, but also the smallest D50 particle sizes. CG had smaller D50 and D84 particles than the average.

Table 4.13. Summary of results from analyzing all sites by grazing type. Italics indicates statistically significant results.

Conventional Grazing	**Managed Grazing**	**Non Grazing**
Most entrenched	*Least entrenched*	*Intermediate entrenchment*
Flattest slopes	*Steepest slopes*	*Intermediate slopes*
Highest BEHI Rating	Lowest BEHI Rating	Intermediate BEHI Rating
Intermediate W/D ratio	Highest W/D ratio	Lowest W/D ratio
Smallest particle size range	Largest particle size range	Intermediate particle size range

Grassed NG sites include the reference reach and site C of the T-7 reach. Wooded NG sites include the southern section of 600th Ave reach and phase 3 of the 300th Ave reach. Among the NG managed areas, the grassed sites had lower width-depth ratios and higher entrenchment ratios (Table H.1). While they have larger D50 particles, they tend to have smaller D84 sizes. Some disparity may be present due to the difference in size and location of the sites.

4.6. Regression Analysis

A summary of all of the regression analyses is shown by Table I.1 in Appendix I. The regression model predicts the following dependent variables because they are the main measurements for characterizing a stream channel.

4.6.1. Width-depth ratio

A significant positive relationship was found between the flood-prone area width and the width-depth ratio (Appendix I.2). This is expected as channels with larger flood-prone area widths tend to have higher width-depth ratios.

4.6.2. Bankfull width

The bankfull width was found to be well-predicted by a combination of the drainage area, mean bankfull depth, maximum depth, D84 particle size (Appendix I.3). It increases with all but the mean bankfull depth. Deeper mean bankfull depths result in narrower bankfull widths. It was also found to have a strong positive relationship with the D50 particle size.

4.6.3. Entrenchment ratio

Drainage area, slope, and the D84 particle size were found to be significant predictors of the entrenchment ratio - slope most of all (Appendix I.5). Entrenchment ratio increases with drainage area and slope, but decreases as D84 particles increase.

4.6.4. BEHI Rating

Finally, the BEHI rating was found to be predictable using a combination of the drainage area, hydraulic radius, and D50 and D84 particle sizes (Appendix I.6). It has a positive relationship with hydraulic radius and D50 particle sizes, but a negative relationship with drainage area and D84 particle sizes.

5. DISCUSSION

5.1. Interpretation of Parameters

The reaches are evaluated by comparing the dimensions between sites. The conditions desirable for a healthy stream are a high entrenchment ratio, larger particle sizes, and a lower BEHI rating. A high entrenchment ratio means that the channel is less entrenched. This means that there is higher floodplain connectivity, which results in less incising of the banks. A larger range of particle sizes is a combination of the desired larger D84 particles and the undesired smaller D50 particles. In these cases, the sediment supply and source should be considered. There may be colluvium entering the channel. Alternatively, larger D84 particles may be due to manmade riprap or boulder riffles. A large ratio between flood-prone area width and bankfull width is desirable. The desirable width-depth ratio may vary based on a number of various factors, and should be evaluated alongside other variables such as bank angle, bank erosion, and channel stage progression to understand the distribution hydraulic stress and therefore erosion on the banks. Larger particles mean there is less fine sediment that could harm aquatic habitats, and that there is a more diverse range of habitat and bed features (Smiley and Dibble, 2005). Lastly, a lower BEHI rating simply means that the banks at that site are less at risk of erosion. It should be noted that these results do not account for upstream land uses, as suspended sediment or other water quality parameters are not evaluated.

5.2. Dobbins Creek Assessment

The NG channel sections are shown to be steeper, have more desirable particle size distributions, are less entrenched, and have lower BEHI ratings, with more significant improvements being seen in the grassed NG area. These attributes indicate less suspended sediments, less bank erosion, and a more stable channel overall. The CG sections had smaller D50 and D84 particle sizes, which indicate greater fine sediments. Flatter slopes indicate less diversity in bed features and aggradation of fine sediments. These slopes, as well as the greater depths and widths of channels in CG sections, can be attributed to the effects of cattle trampling and exposing banks. While grassed, the CG sections still showed poorer results than the wooded NG section. Based on the comparison among Dobbins sites, it could be concluded that grassed NG sections have the healthiest channels, and that wooded NG sections are better than CG sections. NG areas that are properly managed to promote grassy vegetation are associated with the best channel health along this stream.

5.3. Sugarloaf Creek Assessment

All of the changes in site A were desirable. The reduction in the depth of fine sediments is good for aquatic habitat and indicates that there is less erosion. Smaller width-depth ratios are associated with less erosion and bank stress. A larger distribution of particles may not always be positive, but combined with the reduction in fine sediments, it could indicate more diversity in the bed features and healthier bed habitats.

Site B saw some conflicting changes. It saw a larger distribution of particles. However, the depth of fines drastically decreased here, so perhaps the greater distribution of particles is including more fine sediments in this situation.

Site C became more entrenched, as indicated by the lower entrenchment ratio. This is likely due to the channel progression that occurred in the 5 year period. A new channel forming within the old one is a common progression. The decrease in particle sizes may be due to the vulnerable new banks, though the depth of fines is lower as well, indicating that the fine sediments are not being deposited here.

Lastly, site D was the only site to see an increase in the depth of fines. Still, the channel became narrower and smaller since the management changes. The increase in fines and decrease in particle sizes is similar to site C, and may be due to the sites' previous conditions as a wooded, non-grazed area.

This type of intensive management, at least for these sites, has been observed to be effective at improving the stream channel. Greater vegetative cover is desirable to prevent erosion of the banks and fine sediment deposition. More stable banks and narrower channels are great examples of improvements in stability. Lastly, larger pools indicate a healthier bed feature pattern and greater habitat for aquatic life. Switching from CG, as shown in sites A and B, or from NG, like in site D, showed improvements over the observed five year period, more so than keeping an area as NG, represented by site C. While this is a very site-specific study, areas similar in geography and hydrogeology to this site can benefit from and improve on these results.

5.4. Elm Creek Assessment

Keeping the livestock from grazing in the restored area until the bank revegetation project had time to establish may have increased its successfulness. As seen in the NG phase 3, the absence of grazing pressures allowed the sandbar willows and other vegetation to establish and flourish. Implementing a MG strategy would have been even more effective, pruning the willows to promote more shoot growth and allowing grasses and forbs to grow by keeping larger shrubs and trees in check (Wade and Westerfield, 2015). Parts of the restoration project were still successful, such as removal of the mid-channel sandbar. Other aspects of the project were less successful. The failure of the oxbow reconnection is largely due to the aggradation in the channel. This aggradation could be caused in part by the eroding and exposed banks. Having CG conditions surely had a negative impact. This impact is clearly shown by the difference entrenchment ratios between the phases. Phase 3 kept nearly the same entrenchment ratio, while phases 1 and 2 had lower ratios (Table 4.10).

5.5. Overall Assessment

CG sites were clearly shown to be significantly more entrenched and have flatter slopes. This is not desirable for a healthy stream. Greater entrenchment leads to further bank erosion and sediment leakage, and flatter slopes promote deposition of sediment and poor or non-existent habitat. On the other hand, the MG sites showed the best results regarding these two factors.

Though not statistically significant, results worth reporting include differences in BEHI rating, width-depth ratio, and particle size. The lowest BEHI ratings were found in MG sites, further supporting the hypothesis. The larger range of particle sizes present in MG sites is desirable for greater habitat diversity. Having fewer finer particles than CG sites is also an improvement. While keeping in mind the potential differences in the site locations, it could be concluded that MG practices have created more stable banks and decreased erosion by more than NG practices have.

Between the NG sites, it seems that grassed sites have healthier channels than wooded sites. Grassed sites had higher entrenchment ratios and larger particles overall, indicating that there is less erosion.

5.6. Regression Models

The results from the regression model are discussed below. The drainage area is a part of the regression models for bankfull width, entrenchment ratio, and BEHI rating, suggesting that the size of the channel plays a big role regarding these characteristics.

5.6.1. Width-depth Ratio

Larger flood-prone areas having greater width-depth ratios is expected, as receiving flow from greater areas during large storm events means that those streams will carve out wider rivers.

5.6.2. Bankfull Width

Bankfull width was expected to be related strongly to drainage area and bankfull depths. This suggests that larger drainage areas and larger depths in the channel are connected to larger bankfull widths. This is the case for channels with deeper maximum depths and larger drainage areas as well. However, deeper mean bankfull depths result in narrower bankfull widths. It seems that while deeper maximum depths are related to widening, a deeper mean depth is the opposite. This result is likely a spurious relationship and there may be another factor that was not considered. Bankfull width was found to be a strong predictor for the D50 particle size. A larger width causes a larger particle size. This may be related to the drainage area, but that correlation was not found to be very significant. Variables not considered include the volume and velocity of the flow, which could play a role in connecting the particle size to the channel bankfull width.

5.6.3. Entrenchment Ratio

It is no surprise that the entrenchment ratio relies on the drainage area and slope of the channel, but the D84 particle size appears as a significant factor. In this case, a larger D84 decreases the entrenchment ratio, meaning greater entrenchment in the channel. This suggests that the promotion or inclusion of larger particle sizes should be reconsidered, or that channels that are entrenched tend to have larger D84 particle sizes.

5.6.4. BEHI Rating

The BEHI rating was found to decrease for larger drainage areas, increase with a larger hydraulic radius, and increase with D50 but decrease with D84 particle sizes. This is expected as larger channels tend to have less stable banks and fewer fine sediments are a result of more stable banks. However, again the D84 particle size negatively affects a desirable characteristic.

5.6.5. Influential Variables

The variables of reach D84 and drainage area were found to be significant influences of many main dimensions of a channel. While drainage area is hard to change and the size of a river and its flow are expected to be major factors of its properties, reach D84 stands out as being an unexpected variable that can be managed. While the relationship with BEHI rating has a p-value slightly over 0.05, the rest of the relationships are clearly significant. Larger D84 particle sizes have shown to be associated to unstable channels. This is the opposite of what is expected. Generally, larger D84 particles sizes are desirable for stability, habitat, and indicates erosion has lessened. However, this result could also indicate that there have been higher flows or large recent storm events that have washed away the finer particles. This could mean that the channel was eroding and unstable prior to the disturbance, as such an event would have a greater effect on an area with previous erosion problems. This could have resulted in a greater D84 particle size at the time of data collection. Further research and study is recommended on precipitation events and how their intensity and duration affect stream channels. Literature is not as available on this relationship. It would be worth exploring further whether the connection between storm events, D84 particle sizes, and stream channel stability is consistent with other cases.

5.7. Alternatives

Other solutions to the issues of bank stabilization, sediment pollution, and stream health have been considered. In-stream projects such as constructing livestock stream crossings, creating bed features using boulder clusters or large woody debris, artificial step-pools, and bank revegetation as seen at the Elm Creek site all have extensive research and literature regarding when, where, and how they should be implemented. However, in many situations, cost is the limiting factor. Specific site conditions and unique situational factors will also need to be considered first. This may eliminate or reduce the effectiveness and reasoning for implementing many of these solutions. For example, using boulder clusters is most effective only in wide, shallow streams with larger particles (Taylor, 2004). Additionally, some of these solutions can fail due to natural causes such as storm events, or even due to improper construction. Shields et al. 2003 saw progressive failure of large woody debris structures in sand-bed streams, and erosion rates were left unchanged. Finally, the equipment required for such projects can be inaccessible at many smaller sites.

The simpler and more cost-effective solution of management changes should be considered first. This study supports the effectiveness of livestock management changes at improving stream channels. While direct comparisons to other best management practices have yet to be explored, managed grazing had proven to keep up with grazing exclusion solutions.

5.8. Study Limitations

It needs to be acknowledged that this study was limited. More data on more sites and from more dates would greatly improve this study. Data collection done by the same person or entity during the same year would also improve the comparisons between the sites. The characteristics available for study in this project are limited because of equipment and time. Factors not considered such as plant species compositions, vegetative height, soil composition, nearby land use, and fish and benthic IBI scores were excluded because of these constraints, but may be useful in providing new and further insight into the impacts of grazing. However, by including geomorphic variables, this study focuses on the physical integrity of the stream, which can be considered an integral measure of habitat quality (Asmus et al., 2009).

Considering upstream factors for each site could reveal additional information and may affect the results. Evaluating sites downstream of the study sites could also be useful in determining the effects these grazing practices have at a larger scale.

6. CONCLUSION

The primary objective of this study was to survey the effects of three grazing management methods on stream channels in southern Minnesota and evaluate the differences between them. The results of this study found that managed grazing sites were able to match and outperform non-grazing sites, conventional grazing sites had the poorest stream conditions, and grassy vegetation is more desirable than woody vegetation for stabilizing banks and reducing erosion in these settings like those assessed in this study. For small agricultural streams, managed grazing has the potential to outperform grazing exclusion strategies. One of the major benefits of managed grazing is supporting grassy vegetative communities on the stream banks. Information on potential impacts of various grazing strategies can assist landowners and local agencies in making decisions to address the problems associated with riparian pastures and streambank erosion.

Based on the findings in this study, managed grazing is recommended as the preferred grazing strategy instead of conventional or grazing exclusion because: (1) managed grazing showed the best results overall regarding stability, erosion, and morphology of the stream channel; (2) managed grazing promotes grassy bank vegetation, which showed better results than woody bank vegetation sites did regarding stream bank stability and erosion. This in turn supports managed grazing as the better strategy since the grazing of forage by cattle can promote growth of grasses and deny succession by woody species.

Conventional grazing is strongly discouraged as a method for managing riparian pasture because conventional grazing sites consistently showed the worst stream conditions compared to managed and grazing exclusion sites in this study, supporting the findings of past literatures. Regardless of the Sugarloaf Creek and Elm Creek datasets' limitations, the results showed a consistent trend of conventional grazing greatly underperforming compared to grazing exclusion and managed grazing sites.

Smaller reach D84 sizes are shown to be significantly related to narrower widths, less entrenchment, and higher BEHI ratings. In other words, larger D84 particles are found to be associated with channels of greater instability and erosion.

Future research is needed to further compare these types of grazing management. A study comparing various types within managed grazing should also be performed to better understand the differences. To validate these recommendations, a similar study should be performed in which all streams are of a similar size and all stream reaches are surveyed by the same individual or entity. References reaches should be established for each stream. Greater detail and more variables in the survey should also be considered. A better understanding on the impacts of various types of grazing will help to better utilize and protect streams and their riparian areas.

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8. APPENDICES

Appendix A: Field Procedures

A.1. Longitudinal Profile Survey

A longitudinal profile is used to characterize average stream slopes and depths of riffles, pools, runs, and glides. The thalweg and water surface are measured at every point. Bankfull and low bank height measurements are made if there is a good indicator. The slope changes in bed elevation and water surface can be seen as the stream progresses through its bed feature sequences. The surveying was done with a rotary laser level and a grade level rod. First, the laser level instrument is set up with a clear line of sight to a benchmark of known elevation. The laser detector should be attached to the rod. The height of the instrument is then determined using the benchmark elevation and the backsight rod reading. If the stream bends or the line of sight to the instrument is broken for any reason, then a turning point must be made in order to move the instrument. The difference in elevation can be accounted for using the original backsight and the new one. A 300-ft field tape measure is placed along the centerline of the channel and used to obtain stream length stationing. At each station, starting at station 0, measurements are taken for the thalweg and the water surface, as well as the bankfull and low bank height if applicable. This is done for the entire length of the channel of interest, which is usually at least 20 to 30 bankfull channel widths. Measurements should particularly be taken at the start, midpoint, and end of major bed features (Rosgen, 2014). Locations where cross-section measurements were taken are noted so the plots can be referenced together. The average water surface slope can be obtained using a best-fit line through the water surface data points that start and end on two similar bed features. The average bankfull slope is found using a best-fit line through all of the bankfull elevation data points. The stream gradient is more accurate when determined by this method than by using topographic maps. This information is useful for assessing the sediment transport capacity and the shear stress acting on the channel banks (Asmus et al., 2009).

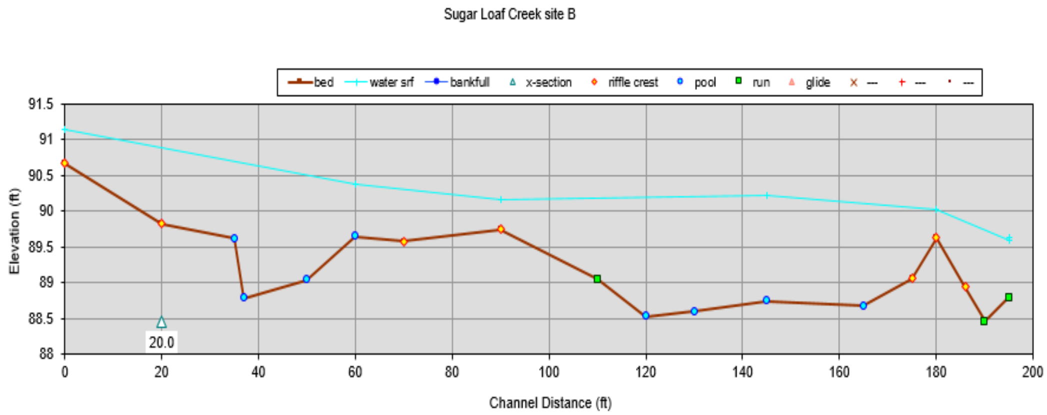


Figure A.1. An example of a longitudinal survey from site B at the T-7 reach on Sugarloaf Creek. Points that were surveyed in the field and entered into a Mecklenburg sheet are used to create this line graph image. Channel and water surface slopes are calculated using this data.

A.2. Cross-section Survey

The ideal location for a cross-section survey is at the narrowest part of a riffle section. It should also be far enough away from any bridges or channel modifications. Cross-sections may also be taken at other bed features for a range of dimensions. Once the location of the cross-section survey is decided, the rotating laser level should be set up in a location where the entire cross-section is in view. It should also be placed at an elevation higher than the highest feature to be included in the survey. If there is dense foliage, more than one set up may be required. A field tape measure is stretched across the channel, with 0 being on the left bank, and kept perpendicular to the bankfull discharge flow. A backsight of a benchmark should be taken for future reference, and the height of the instrument can be calculated with the elevation of a benchmark, known or relative. All measurements will be adjusted based on the surveyed benchmark. Rod readings are then taken at major breaks in bed elevation and key features, including left bankfull, left edge water, thalweg, right edge water, and right bankfull. The dimensions in the equations below can be determined from a plot of this cross-section survey data. For riffle cross-sections, the flood-prone area width should also be measured for the entrenchment ratio calculation. The cross-sectional area should also be checked against an appropriate regional curve to make sure it is reasonable. For pool cross-sections, the point bar slope should be measured as well.

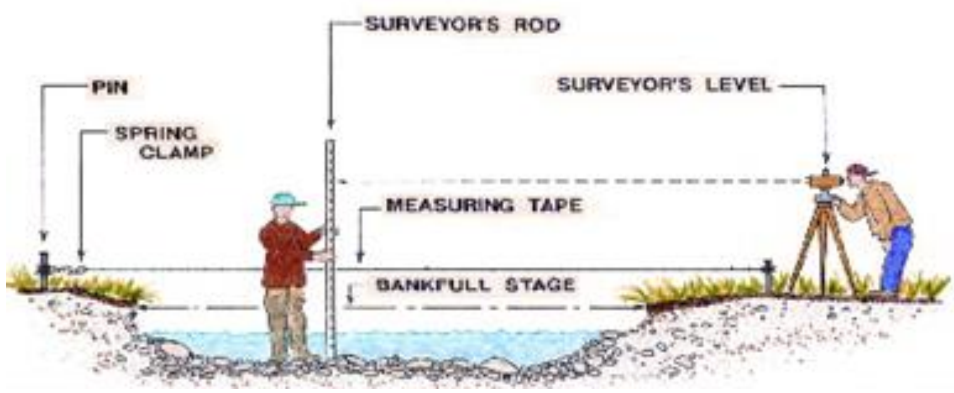


Figure A.2. Example of cross-section survey (Rosgen, 2014).

Cross-section data at riffle bed features provide most of the morphological parameters needed for stream classification. These include the bankfull width, bankfull mean depth, bankfull maximum depth, bankfull cross-sectional area, width/depth ratio, entrenchment ratio, flood-prone area width, and Rosgen channel type. Surveying multiple of each bed feature allow for a range of dimensions. Pool and glide cross-sections provide data for the dimensions of the inner berm, which represents the low flow channel boundary. These dimensions are also automatically calculated when the cross-sectional data is entered into RIVERMorph or Mecklenberg data sheets. Each cross-section is shown as a line graph (Figure A.3). Bankfull and flood-prone widths are calculated using the survey data.

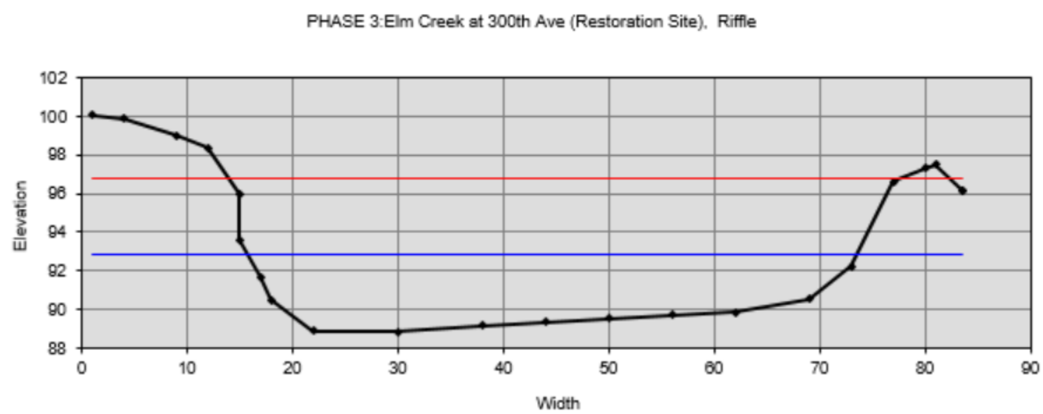


Figure A.3. An example of a cross-section survey at the phase 3 site in the 300th Ave reach of Elm Creek. Points that were surveyed in the field and entered into a Mecklenburg sheet are used to create this line graph image. The lines represent the bankfull and water surface levels.

A.3. Pebble Count Survey

The morphological description of a reach requires two types of pebble counts; representative and active bed riffle. The representative pebble count characterizes the bed material present through a reach to classify the stream type. The active bed riffle pebble count is used for hydraulic calculations to estimate velocity on the riffle bed and to calculate sediment competence. The representative pebble count is used to proportionally sample all the bed features within a designated reach. Particles are collected at evenly spaced intervals along the entire bankfull channel. To avoid bias of selecting larger particles, the sampler should look away select the first particle touched. The length of the intermediate axis is measured, unless it is linear-shaped, then the average of all axes is used. At least 10 particles are measured at 10 total transects, giving a total of 100 particles sampled in the reach. The active bed riffle pebble count follows the same method, except that the 100 samples are only taken from the active bed at a riffle cross-section. The percent distribution of particle size classes is calculated once the data is input into RIVERMorph. D50 and D84 represent the average of the 50th and 84th percentiles of particles. If the D50 or D84 are < 0.062 mm, the reach is dominated by silt/clay; 0.062 to 2 mm is dominated by sand; 2 to 64mm is dominated by gravel; and > 64 mm is dominated by cobble and boulder.

Data | Linear Graph | Bar Graph   Date: 07/26/2017

Size (mm)	TOT #	ITEM %	CUM %
0 - 0.062	14	13.21	13.21
0.062 - 0.125	19	17.92	31.13
0.125 - 0.25	22	20.75	51.89
0.25 - 0.50	18	16.98	68.87
0.50 - 1.0	10	9.43	78.30
1.0 - 2.0	8	7.55	85.85
2.0 - 4.0	6	5.66	91.51
4.0 - 5.7	4	3.77	95.28
5.7 - 8.0	0	0.00	95.28
8.0 - 11.3	1	0.94	96.23
11.3 - 16.0	1	0.94	97.17
16.0 - 22.6	0	0.00	97.17
22.6 - 32.0	1	0.94	98.11
32 - 45	1	0.94	99.06
45 - 64	0	0.00	99.06
64 - 90	0	0.00	99.06
90 - 128	0	0.00	99.06
128 - 180	0	0.00	99.06
180 - 256	1	0.94	100.00
256 - 362	0	0.00	100.00
362 - 512	0	0.00	100.00
512 - 1024	0	0.00	100.00
1024 - 2048	0	0.00	100.00
Bedrock	0	0.00	100.00

Particle Size Analysis

D16 (mm)	0.07
D35 (mm)	0.15
D50 (mm)	0.24
D84 (mm)	1.75
D95 (mm)	5.57
D100 (mm)	255.99
Silt/Clay (%)	13.21
Sand (%)	72.64
Gravel (%)	13.21
Cobble (%)	0.94
Boulder (%)	0
Bedrock (%)	0

Total Particles = 106

D 50 0.24 mm

Figure A.4. An example of a particle size distribution generated from a pebble count in reach 3 at the 600th Ave reach of Dobbins Creek.

A.4. Bank Erosion Hazard Index

The BEHI assessment (Rosgen, 2006) is applied to banks of interest along each reach. Eight measurements are made to predict a bank's potential erodibility. The study bank height (ft), bankfull height (ft), root depth (ft), root density (%), bank angle (degrees), surface protection (%), bank material, and stratification of bank material are determined and converted into ratios. Each ratio can then be converted to a BEHI score, which are summed to determine a total BEHI score and adjective rating of 'very low', 'low', 'moderate', 'high', 'very high', or 'extreme' risk of erosion.

Bank height, bankfull height, and root depth were measured using tape measures and rulers. Root density, bank angle, and surface protection were visually estimated. Bank material was determined through observation of the soil's color, texture, and size. Bank material stratification could be visually observed.

A.5. Near-bank Stress

NBS assessments provide seven options with varying levels of detail. However, a higher level does not guarantee greater reliability. Each method has its own conversion from value to NBS rating, ranging from "very low" to "extreme". Level I only involves reconnaissance, looking at the pattern of the channel and looking for a transverse or central bar to indicate a split channel. Level II compares various measurements such as radius of curvature to bankfull width, or pool slope to water surface slope or riffle slope. Level III compares near-bank and bankfull depth or shear stress for a more detailed prediction. Lastly, Level IV compares velocity gradients. The methods used in this study are all from Level II because the required measurements are the most easily available through the applied data collection process.

Other studies such as Ghosh et al. (2016) have found NBS assessments to be less effective. Only one of the seven NBS methods were an effective predictor of bank erosion on the Bakreshwar River in eastern India. It was concluded that further assessment would be needed to adjust the NBS rating system for their particular site.

Appendix B: Overall Datasets

Table B.1. Overall morphological dataset part 1.

ID	Date	Reach_Name	Creek	Section	Graz	DA	BKF_W	Mean_BKF_D	Max_D
1	2017	600th Ave	Dobbins	Central	CG	9.95	15.12	2.97	4.74
2	2017	600th Ave	Dobbins	Central	CG	9.95	11.43	1.81	3.01
3	2017	600th Ave	Dobbins	Central	CG	9.95	30.46	1.42	4.08
4	2017	600th Ave	Dobbins	Central	CG	9.95	23.35	2.01	3.41
5	2017	600th Ave	Dobbins	Central	CG	9.95	17.09	2.97	4.21
6	2017	600th Ave	Dobbins	Central	CG	9.95	13.37	2.63	3.85
7	2017	600th Ave	Dobbins	Central	CG	9.95	20.56	2.02	4.18
8	2017	600th Ave	Dobbins	Central	CG	9.95	14.03	1.96	3.42
9	2017	600th Ave	Dobbins	Northern	CG	9.95	24.2	1.79	3.56
10	2017	600th Ave	Dobbins	Northern	CG	9.95	24.21	2.04	4.28
11	2017	600th Ave	Dobbins	Northern	CG	9.95	17.29	2.78	4.25
12	2017	600th Ave	Dobbins	Northern	CG	9.95	21.29	2.39	4.69
13	2017	600th Ave	Dobbins	Northern	CG	9.95	20.67	2.3	3.22
14	2017	600th Ave	Dobbins	Northern	CG	9.95	24.52	1.57	2.87
15	2017	600th Ave	Dobbins	Northern	CG	9.95	15.43	2.36	3.87
16	2017	600th Ave	Dobbins	Southern	NG	9.95	26	1.87	2.64
17	2017	600th Ave	Dobbins	Southern	NG	9.95	13.49	2.58	3.43
18	2017	Reference	Dobbins	Christian	NG	5.65	8.13	2.02	2.87
19	2017	Reference	Dobbins	Christian	NG	5.65	14.52	1.81	3.24
20	2017	Reference	Dobbins	Christian	NG	5.65	12	1.9	3.5
21	2004	T-7	Sugarloaf	Site A	CG	7.5			
22	2010	T-7	Sugarloaf	Site A	MG	7.5	36	0.57	4.18
23	2004	T-7	Sugarloaf	Site B	CG	7.5			
24	2010	T-7	Sugarloaf	Site B	MG	7.5	28.6	0.82	1.99
25	2005	T-7	Sugarloaf	Site C	NG	7.5			
26	2010	T-7	Sugarloaf	Site C	NG	7.5	31.4	2.06	5.11
27	2005	T-7	Sugarloaf	Site D	NG	7.5			
28	2010	T-7	Sugarloaf	Site D	MG	7.5	25	0.88	3.31
29	2009	300th Ave	Elm	Phase 1	CG	272	57.7	3.92	5
30	2009	300th Ave	Elm	Phase 2	CG	272	70.6	3.53	4.58
31	2009	300th Ave	Elm	Phase 3	NG	272	63.3	4.25	6.17
32	2009	300th Ave	Elm	Phase 3	NG	272	57.72	3.12	3.98
33	2006	300th Ave	Elm		CG	260	65.6	4.47	5.4

Table B.2. Overall morphological dataset part 2.

ID	BKF_A	WDRatio	W_FPA	Ent_Ratio	Hyd_Rad	WS_Slope	Valley_L	Channel_L	Sinuosity
1	44.93	5.09	125.75	8.317	2.28	0.00017	552.6	606.94	1.098
2	20.71	6.31	44.87	3.926	1.09	0.00091	520.7	747.29	1.435
3	43.37	21.45	139.65	4.585	1.21	0.00091	520.7	747.29	1.435
4	47.01	11.62	71.43	3.059	1.73	0.00091	520.7	747.29	1.435
5	50.68	5.75	76.39	4.47	2.15	0.00061	394.7	726.04	1.839
6	35.23	5.08	52.16	3.901	2	0.00061	394.7	726.04	1.839
7	41.49	10.18	95.25	4.633	1.72	0.00061	394.7	726.04	1.839
8	27.44	7.16	69.29	4.939	1.46	0.00017	552.6	606.94	1.098
9	43.43	13.52	176.66	7.3	1.65	0.00031	432.8	653.5	1.51
10	49.49	11.87	66.6	2.75	1.66	0.00123	484.2	543.47	1.122
11	48.08	6.22	56.82	3.29	2.32	0.00171	392.7	651.24	1.658
12	50.87	8.91	75.13	3.53	2.03	0.00101	521.4	573.47	1.1
13	47.45	8.99	62.8	3.04	1.98	0.00101	521.4	573.47	1.1
14	38.55	15.62	77.94	3.18	1.46	0.00031	432.8	653.5	1.51
15	36.35	6.54	94.91	6.15	2.01	0.00031	432.8	653.5	1.51
16	48.72	13.9	30	1.15	1.78	0.0015	587	605	1.031
17	34.76	5.23	40.3	2.987	1.97	0.00061	394.7	726.04	1.839
18	16.43	4.024752475	43.09	5.3	1.350041085	0.00201	605	1073	1.54
19	26.26	8.022099448	43.09	5.3	1.447629548	0.00201	605	1073	1.54
20	22.8	6.315789474	43.09	5.3	1.443037975	0.00201	605	1073	1.54
21	7.427098	17				0.0058			
22	20.52	14.3	280	7.777777778	0.502964279	0.0085	584	661	1.131849315
23	42.30217	16.7				0.0077			
24	23.452	20.8	233	8.146853147	0.751114899	0.0098	191	206	1.078534031
25	21.42018	8.6				0.003			
26	64.684	9.4	304	9.681528662	1.700940301	0.0085	436	498	1.142201835
27	28.20145	12.8				0.0062			
28	22	11.3	272.9	10.916	0.74977148	0.002	816	850	1.041666667
29	213.2	15.6	280	4.852686308	3.5	0.0011	140	141	1.007142857
30	249.29	20.01	412	5.835694051	3.210018027	0.0013	397	665	1.335341365
31	268.81	14.88	454	7.172195893	3.743871866	0.0001	489.9	569.1	1.161665646
32	180.32	18.48	424	7.345807346	2.819262039	0.0001	489.9	569.1	1.161665646
33	293	14.7	500	7.62195122	4.2	0.00093			

Table B.3. Overall morphological dataset part 3.

ID	ReachD50	ReachD84	RiffleD50	RiffleD84	BEHI_Rating	Rosgen_Class
1	0.24	0.77	0.23	0.69	38	E
2	0.08	2.49	0.2	4.11	35.7	E
3	0.08	2.49	0.2	4.11	29.3	C
4	0.08	2.49	0.2	4.11	29.3	E
5	0.15	6.71	0.94	7.08	27.4	E
6	0.15	6.71	0.94	7.08	33.3	E
7	0.15	6.71	0.94	7.08	36.6	E
8	0.24	0.77	0.23	0.69	23.4	E
9	0.55	2.36	0.34	1.12	38.7	C
10	0.24	5.93	6.97	15.29	36.9	E
11	0.29	5.21	0.43	1.82	39.4	E
12	0.24	1.75	0.35	1.6	37.7	E
13	0.24	1.75	0.35	1.6	44.9	E
14	0.55	2.36	0.34	1.12	33.3	C
15	0.55	2.36	0.34	1.12	36.8	E
16	0.33	24.48			26.2	F
17	0.15	6.71	0.94	7.08	35.8	E
18	0.68	6.62	13.65	29.24		E5
19	0.68	6.62	13.65	29.24		E5
20	0.68	6.62	13.65	29.24		E5
21	0.062	13				
22	0.3	12			24	C4
23	0.19	16				
24	0.081	26			28	C5
25	9	25				
26	0.062	0.2			41	B5
27	9	25				
28	0.077	1.4			35	B5
29			6.4	21		
30	4	22	0.5	97	35	C4
31	0.32	4.7			29.5	C4
32	0.32	4.7			21.5	C4
33	1.1	37				

Table B.4. Standardized overall geomorphological dataset part 1.

ID	Date	Reach_Name	Creek	Section	Graz	DA	BKF_W	Mean_BKF_D	Max_D
1	2017	600th Ave	Dobbins	Central	CG	-0.404	-0.707841	0.708637442	0.933296
2	2017	600th Ave	Dobbins	Central	CG	-0.404	-0.915593	-0.525881644	-0.984127
3	2017	600th Ave	Dobbins	Central	CG	-0.404	0.1558183	-0.940935475	0.201794
4	2017	600th Ave	Dobbins	Central	CG	-0.404	-0.244483	-0.313033526	-0.540792
5	2017	600th Ave	Dobbins	Central	CG	-0.404	-0.596928	0.708637442	0.345878
6	2017	600th Ave	Dobbins	Central	CG	-0.404	-0.806368	0.346795641	-0.053124
7	2017	600th Ave	Dobbins	Central	CG	-0.404	-0.401563	-0.30239112	0.312627
8	2017	600th Ave	Dobbins	Central	CG	-0.404	-0.76921	-0.366245555	-0.529709
9	2017	600th Ave	Dobbins	Northern	CG	-0.404	-0.196627	-0.547166456	-0.374541
10	2017	600th Ave	Dobbins	Northern	CG	-0.404	-0.196064	-0.281106308	0.423461
11	2017	600th Ave	Dobbins	Northern	CG	-0.404	-0.585668	0.50643173	0.390211
12	2017	600th Ave	Dobbins	Northern	CG	-0.404	-0.360463	0.091377899	0.877879
13	2017	600th Ave	Dobbins	Northern	CG	-0.404	-0.39537	-0.004403754	-0.751376
14	2017	600th Ave	Dobbins	Northern	CG	-0.404	-0.178611	-0.781299386	-1.139294
15	2017	600th Ave	Dobbins	Northern	CG	-0.404	-0.690388	0.059450681	-0.030957
16	2017	600th Ave	Dobbins	Southern	NG	-0.404	-0.095285	-0.462027208	-1.394212
17	2017	600th Ave	Dobbins	Southern	NG	-0.404	-0.799612	0.293583611	-0.518625
18	2017	Reference	Dobbins	Christian	NG	-0.449	-1.101386	-0.30239112	-1.139294
19	2017	Reference	Dobbins	Christian	NG	-0.449	-0.741622	-0.525881644	-0.729209
20	2017	Reference	Dobbins	Christian	NG	-0.449	-0.883501	-0.430099991	-0.441042
21	2004	T-7	Sugarloaf	Site A	CG	-0.43			
22	2010	T-7	Sugarloaf	Site A	MG	-0.43	0.4677266	-1.845539977	0.312627
23	2004	T-7	Sugarloaf	Site B	CG	-0.43			
24	2010	T-7	Sugarloaf	Site B	MG	-0.43	0.0510981	-1.579479829	-2.114631
25	2005	T-7	Sugarloaf	Site C	NG	-0.43			
26	2010	T-7	Sugarloaf	Site C	NG	-0.43	0.2087414	-0.259821496	1.343381
27	2005	T-7	Sugarloaf	Site D	NG	-0.43			
28	2010	T-7	Sugarloaf	Site D	MG	-0.43	-0.151586	-1.515625394	-0.651626
29	2009	300th Ave	Elm	Phase 1	CG	2.3548	1.6894615	1.719666004	1.221464
30	2009	300th Ave	Elm	Phase 2	CG	2.3548	2.4157463	1.304612173	0.755962
31	2009	300th Ave	Elm	Phase 3	NG	2.3548	2.0047479	2.070865399	2.518218
32	2009	300th Ave	Elm	Phase 3	NG	2.3548	1.6905875	0.868273531	0.09096
33	2006	300th Ave	Elm		CG	2.2285	2.1342406	2.304998329	1.664799
Avg						0	0	-4.44089E-16	0
Stdev						1	1	1	1

Table B.5. Standardized overall geomorphological dataset part 2.

ID	BKF_A	WDRatio	W_FPA	Ent_Ratio	Hyd_Rad	WS_Slope	Valley_L	Channel_L	Sinuosity
1	-0.28452	-1.25214495	-0.2400121	1.268321676	0.40344274	-0.74384968	0.56907056	-0.28659326	-0.93711762
2	-0.59776	-1.01025091	-0.8038844	-0.63768942	-0.9613581	-0.47808802	0.32266091	0.395596397	0.268576496
3	-0.3047	1.99161439	-0.1431053	-0.35163583	-0.82373112	-0.47808802	0.32266091	0.395596397	0.268576496
4	-0.25762	0.042582955	-0.6187157	-1.01403003	-0.22734756	-0.47808802	0.32266091	0.395596397	0.268576496
5	-0.21016	-1.12128424	-0.584136	-0.401554135	0.25434685	-0.58582923	-0.6506186	0.292307974	1.713978344
6	-0.40997	-1.25412768	-0.7530606	-0.648541225	0.08231313	-0.58582923	-0.6506186	0.292307974	1.713978344
7	-0.32901	-0.24293131	-0.4526494	-0.330800364	-0.23881648	-0.58582923	-0.6506186	0.292307974	1.713978344
8	-0.51072	-0.84171818	-0.6336351	-0.197974266	-0.53700826	-0.74384968	0.56907056	-0.28659326	-0.93711762
9	-0.30392	0.419303171	0.1149179	0.826870233	-0.31909888	-0.69357044	-0.3563174	-0.060282249	0.536906047
10	-0.22555	0.092151404	-0.652389	-1.148158345	-0.30762996	-0.36316406	0.04071884	-0.595097553	-0.85125216
11	-0.24378	-1.02809555	-0.7205724	-0.913759349	0.4493184	-0.19077812	-0.6660675	-0.071267276	1.066409694
12	-0.2077	-0.49473904	-0.5929203	-0.809582017	0.11671988	-0.44217428	0.32806802	-0.449278602	-0.92996217
13	-0.25193	-0.47887713	-0.6788816	-1.022277402	0.0593753	-0.44217428	0.32806802	-0.449278602	-0.92996217
14	-0.36704	0.835678147	-0.5733298	-0.961507292	-0.53700826	-0.69357044	-0.3563174	-0.060282249	0.536906047
15	-0.39549	-0.96464794	-0.4550198	0.327687186	0.09378205	-0.69357044	-0.3563174	-0.060282249	0.536906047
16	-0.23551	0.494647214	-0.9075538	-1.842673889	-0.17000299	-0.26619697	0.83479131	-0.296022885	-1.17682535
17	-0.41605	-1.22438661	-0.8357451	-1.04528323	0.04790639	-0.58582923	-0.6506186	0.292307974	1.713978344
18	-0.65312	-1.46335562	-0.8162941	-0.041274197	-0.6631192	-0.08303691	0.97383123	1.978752744	0.644237867
19	-0.52598	-0.67078645	-0.8162941	-0.041274197	-0.55119582	-0.08303691	0.97383123	1.978752744	0.644237867
20	-0.57073	-1.00910301	-0.8162941	-0.041274197	-0.55646186	-0.08303691	0.97383123	1.978752744	0.644237867
21	-0.76955	1.109295988				1.278093723			
22	-0.60022	0.573956734	0.8353749	1.034260291	-1.63462435	2.247764625	0.81161798	-0.023827511	-0.816014
23	-0.31851	1.049813849				1.960454728			
24	-0.5623	1.862736421	0.5077043	1.194465654	-1.35002253	2.714643207	-2.2240871	-2.235414928	-1.00676155
25	-0.58858	-0.55620392				0.272509084			
26	-0.02904	-0.39758488	1.0026961	1.860625655	-0.26067588	2.247764625	-0.3315992	-0.816110476	-0.77897551
27	-0.50088	0.276546037				1.421748671			
28	-0.58108	-0.02086466	0.7858757	2.396475362	-1.35156328	-0.08662829	2.60368815	0.894831878	-1.13866293
29	1.891733	0.831712671	0.8353749	-0.235440642	1.80265032	-0.40985192	-2.6180335	-2.551355987	-1.2621797
30	2.358489	1.706100121	1.7556413	0.191255707	1.47007247	-0.33802445	-0.6328524	-0.004384984	-0.08797493
31	2.610944	0.688955537	2.0484533	0.771394021	2.08234488	-0.76898929	0.08474815	-0.470519563	-0.7093393
32	1.466492	1.40274121	1.8393019	0.846753929	1.02191777	-0.76898929	0.08474815	-0.470519563	-0.7093393
33	2.923796	0.653266253	2.3691522	0.966620312	2.60547435	-0.47090527			
Avg	0	1.14387E-16	1.225E-16	6.73791E-16	-1.3782E-16	-6.8968E-17	3.2613E-16	1.14591E-15	-1.3798E-15
Stdev	1	1	1	1	1	1	1	1	1

Table B.6. Standardized overall geomorphological dataset part 3.

ID	ReachD50	ReachD84	RiffleD50	RiffleD84	BEHI_Rating	Rosgen_Class
1	-0.326428861	-0.86872053	-0.558639289	-0.56419722	0.795527999	E
2	-0.39852427	-0.687790504	-0.564818059	-0.406486387	0.414668107	E
3	-0.39852427	-0.687790504	-0.564818059	-0.406486387	-0.64511594	C
4	-0.39852427	-0.687790504	-0.564818059	-0.406486387	-0.64511594	E
5	-0.366982529	-0.243880789	-0.412408393	-0.269526979	-0.959739329	E
6	-0.366982529	-0.243880789	-0.412408393	-0.269526979	0.017249089	E
7	-0.366982529	-0.243880789	-0.412408393	-0.269526979	0.563700239	E
8	-0.326428861	-0.86872053	-0.558639289	-0.56419722	-1.622104358	E
9	-0.186744006	-0.701465448	-0.535983798	-0.54436808	0.911441879	C
10	-0.326428861	-0.325930452	0.829524421	0.109071249	0.613377616	E
11	-0.303899046	-0.401668603	-0.517447487	-0.512088085	1.027355759	E
12	-0.326428861	-0.765632492	-0.533924208	-0.522233226	0.745850622	E
13	-0.326428861	-0.765632492	-0.533924208	-0.522233226	1.938107674	E
14	-0.186744006	-0.701465448	-0.535983798	-0.54436808	0.017249089	C
15	-0.186744006	-0.701465448	-0.535983798	-0.54436808	0.59681849	E
16	-0.285875194	1.625378841			-1.158448838	F
17	-0.366982529	-0.243880789	-0.412408393	-0.269526979	0.431227233	E
18	-0.128166487	-0.253348058	2.20533059	0.752365436		E5
19	-0.128166487	-0.253348058	2.20533059	0.752365436		E5
20	-0.128166487	-0.253348058	2.20533059	0.752365436		E5
21	-0.406635004	0.417776109				
22	-0.299393083	0.312584233			-1.522749604	C4
23	-0.348958676	0.733351735				
24	-0.398073674	1.785270492			-0.860384575	C5
25	3.620794777	1.680078616				
26	-0.406635004	-0.928679899			1.292301771	B5
27	3.620794777	1.680078616				
28	-0.399876059	-0.802449649			0.298754227	B5
29			0.712127787	0.37238378		
30	1.367813248	1.364502989	-0.503030357	3.877068958	0.298754227	C4
31	-0.290381157	-0.455316459			-0.611997689	C4
32	-0.290381157	-0.455316459			-1.936727747	C4
33	0.061083962	2.942381124				
Avg	-1.33574E-16	1.38778E-16	0	0	0	
Stdev	1	1	1	1	1	

Appendix C: Dobbins Creek Data

Figure C.1. Map of the cross-section surveys.

Figure C.2. Cross-section 1 plot from RIVERMorph.

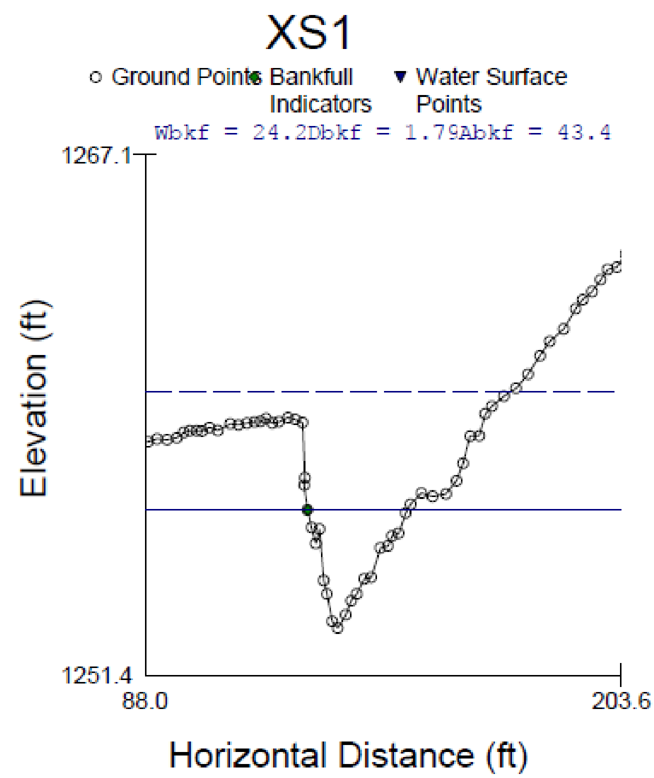


Figure C.3. Cross-section 3 plot from RIVERMorph.

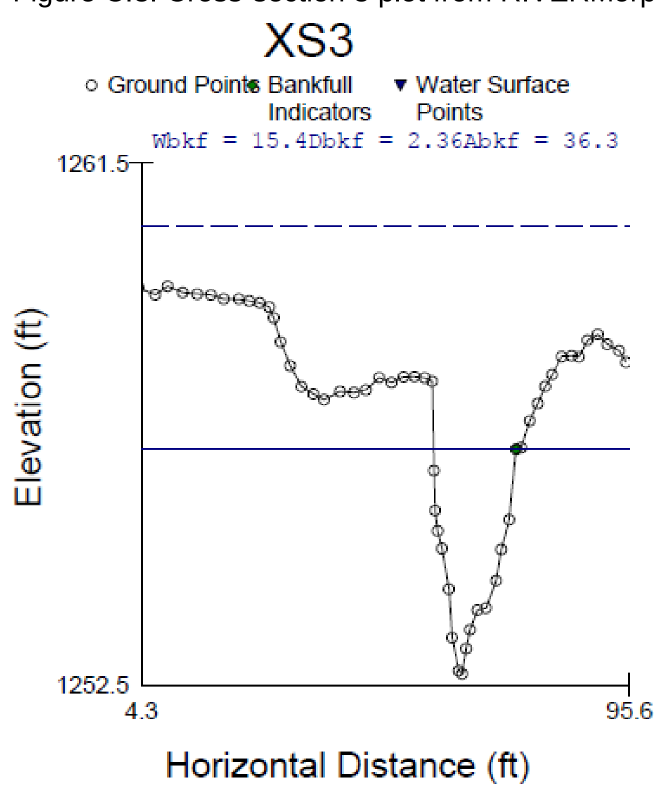


Figure C.4. Cross-section 2 plot from RIVERMorph.

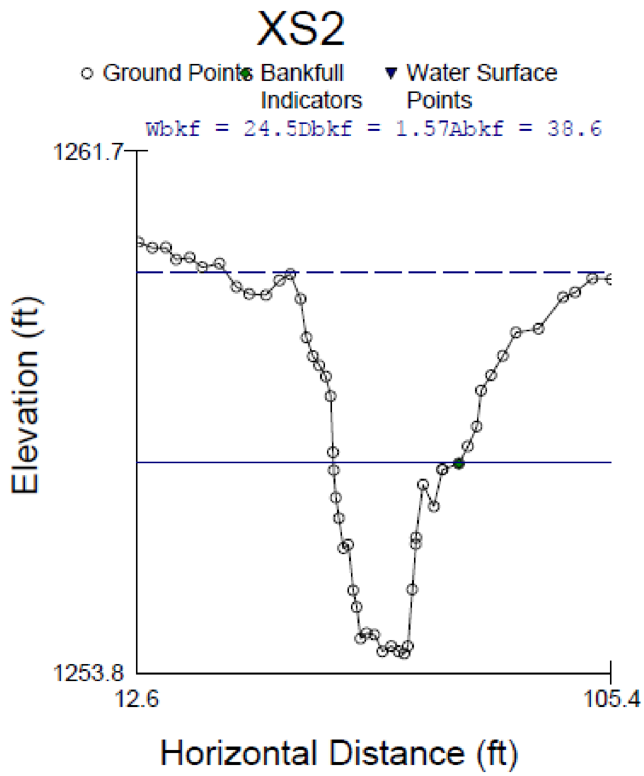


Figure C.5. Cross-section 5 plot from RIVERMorph.

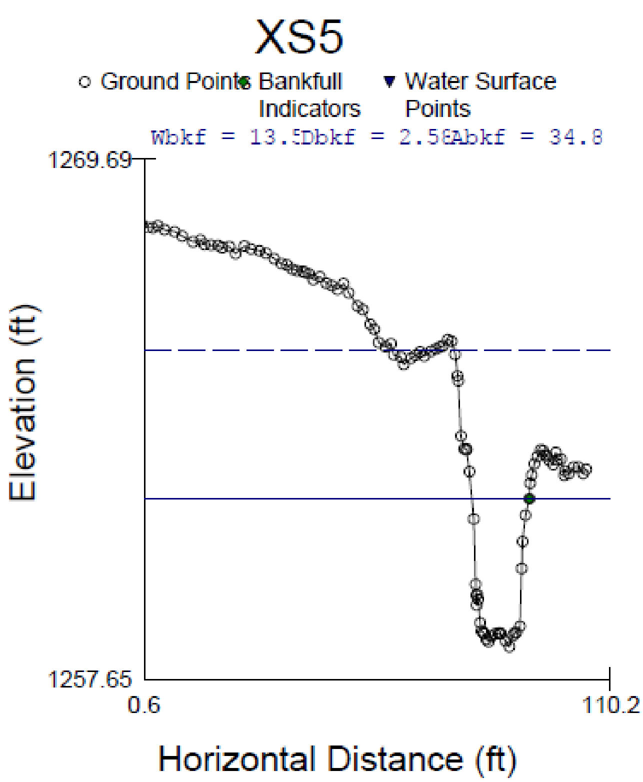


Figure C.6. Cross-section 6 plot from RIVERMorph.

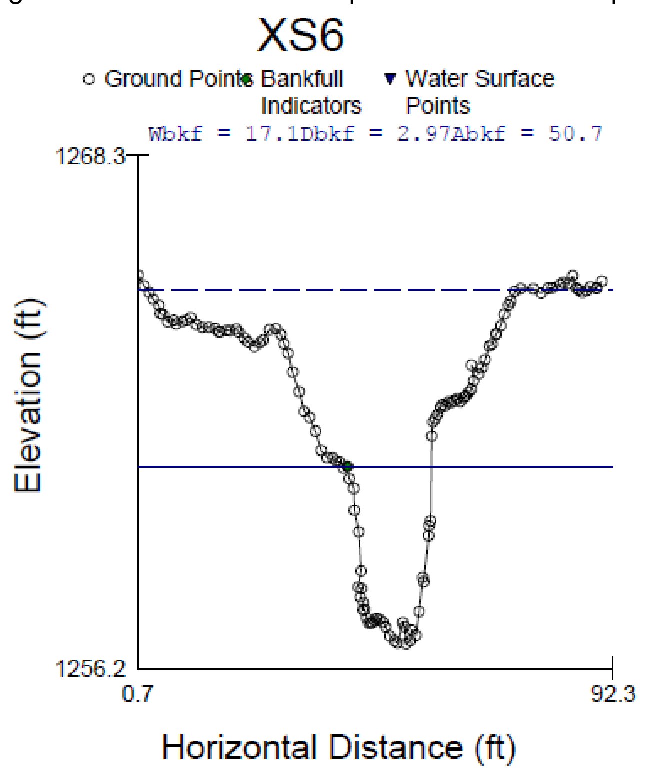


Figure C.7. Cross-section 7 plot from RIVERMorph.

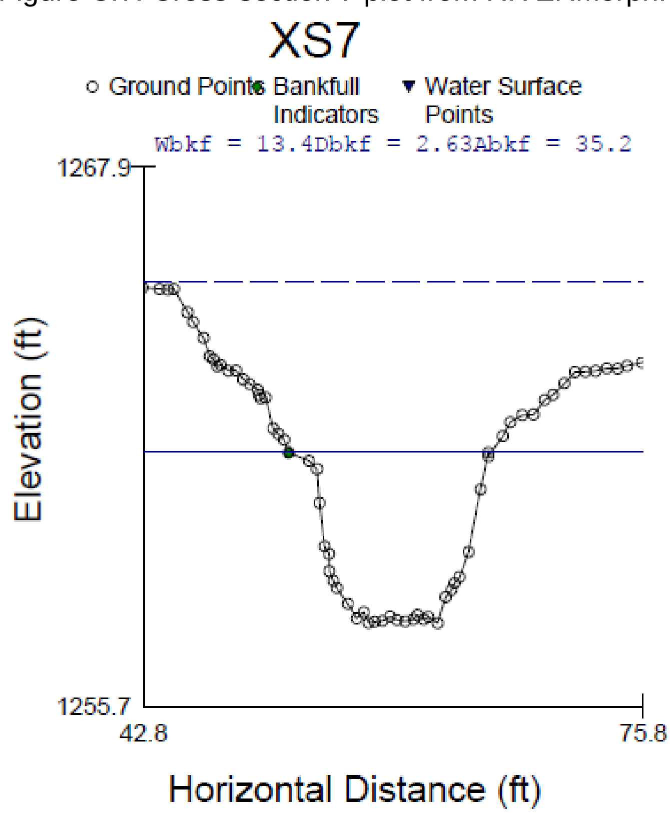


Figure C.8. Cross-section 8 plot from RIVERMorph.

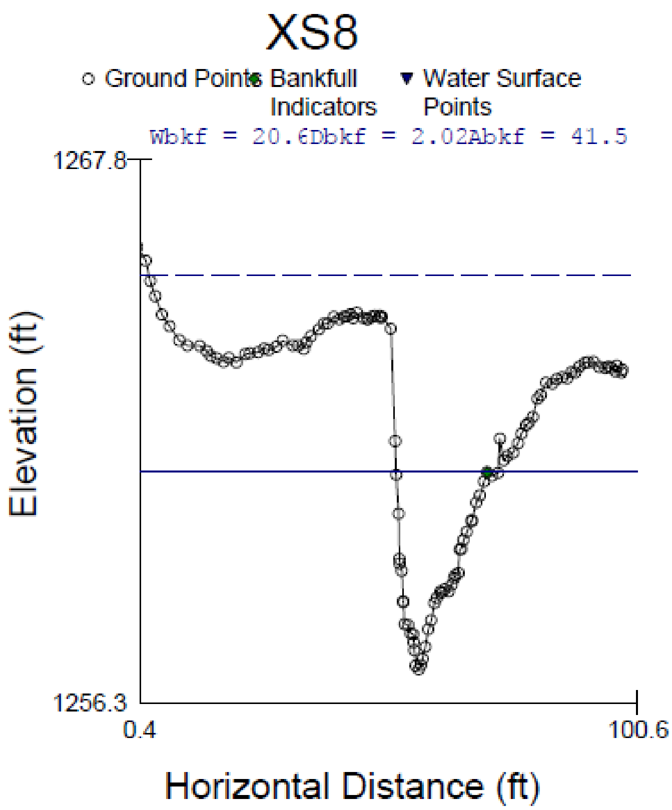


Figure C.9. Cross-section 9 plot from RIVERMorph.

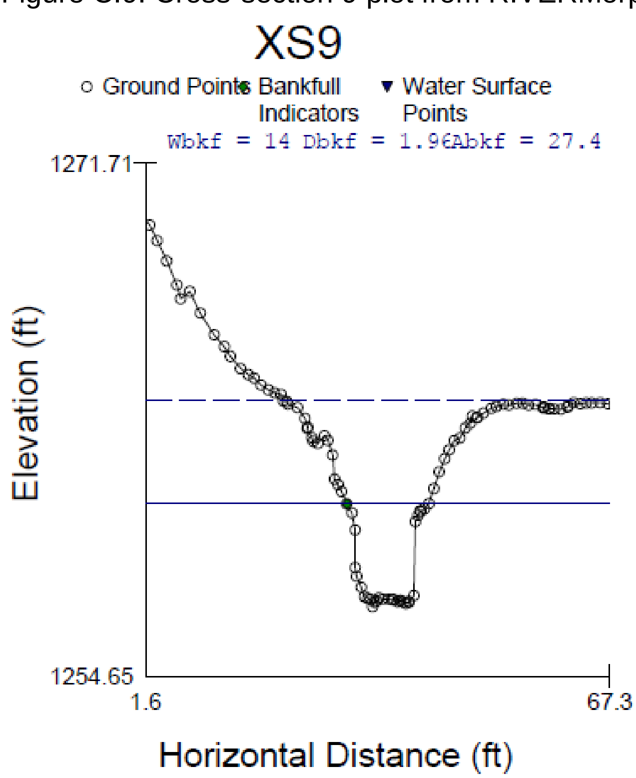


Figure C.10. Cross-section 10 plot from RIVERMorph.

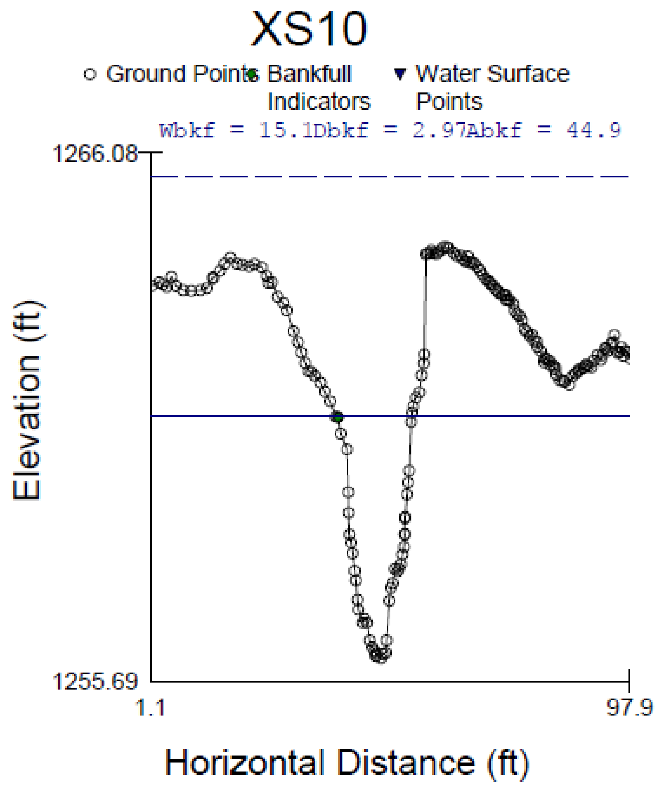


Figure C.11. Cross-section 11 plot from RIVERMorph.

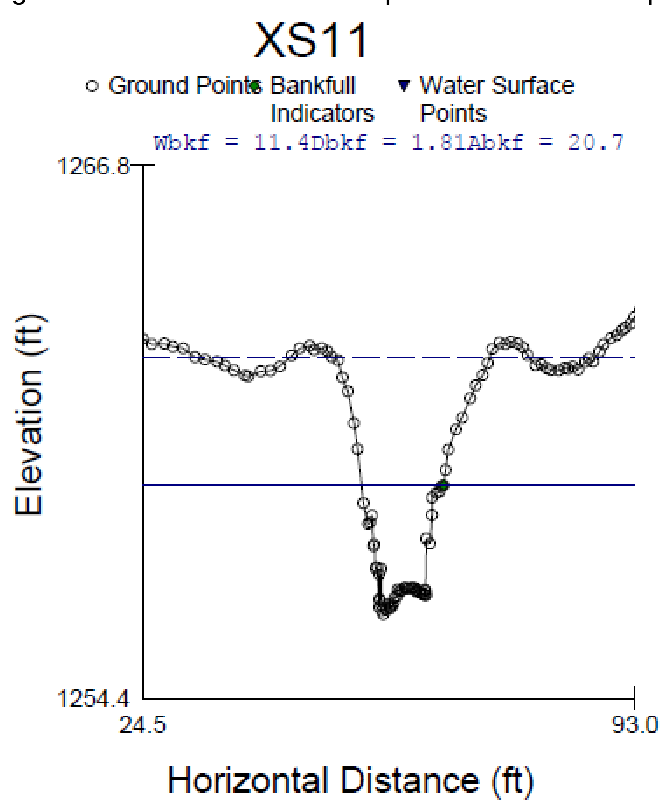


Figure C.12. Cross-section 12 plot from RIVERMorph.

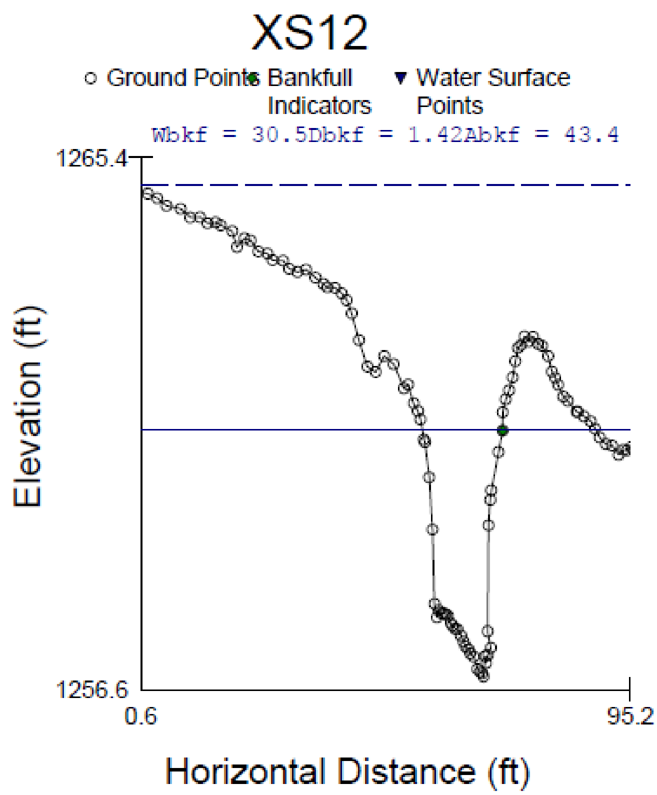


Figure C.13. Cross-section 13 plot from RIVERMorph.

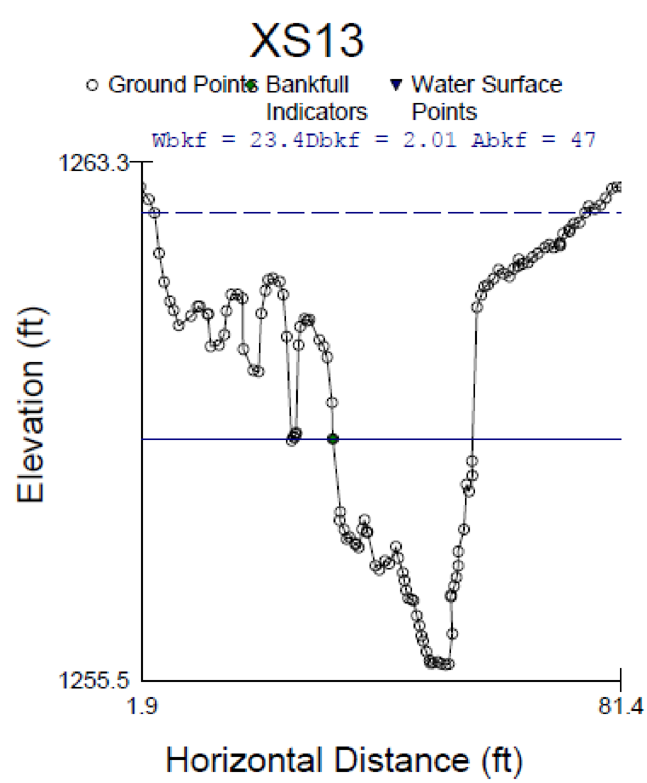


Figure C.14. Cross-section 14 plot from RIVERMorph.

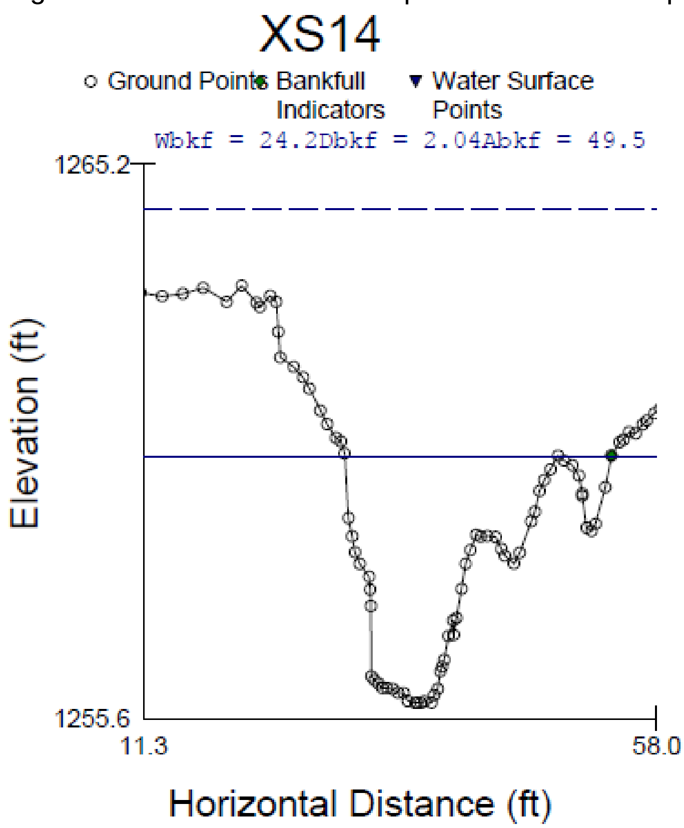


Figure C.15. Cross-section 15 plot from RIVERMorph.

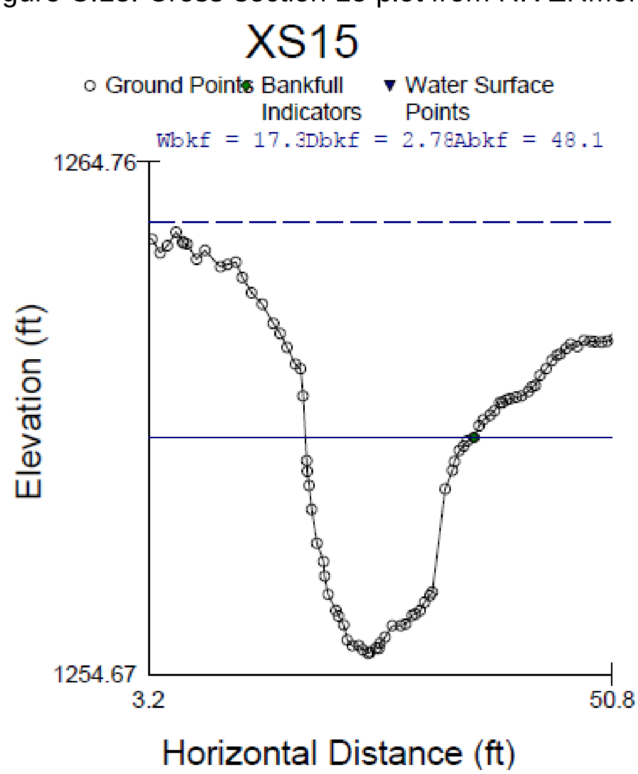


Figure C.16. Cross-section 16 plot from RIVERMorph.

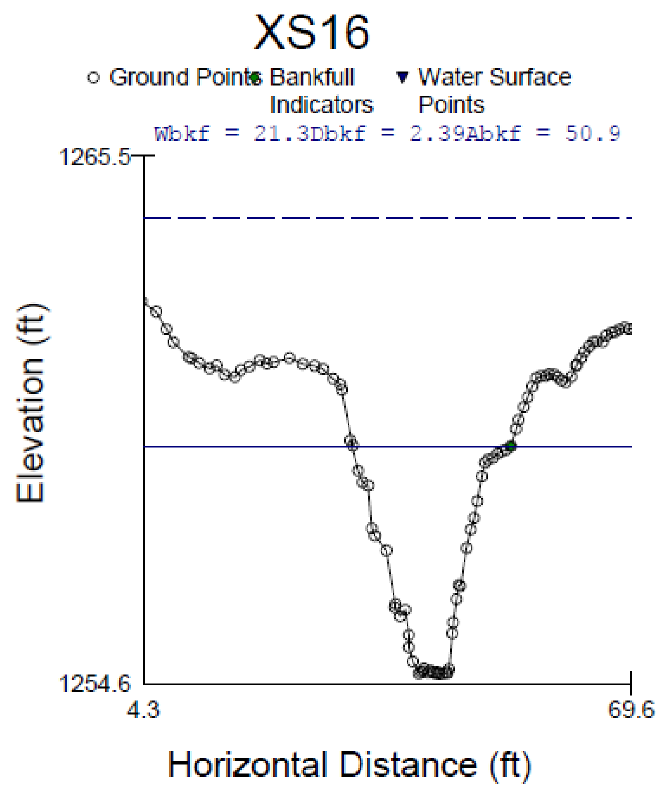


Figure C.17. Cross-section 17 plot from RIVERMorph.

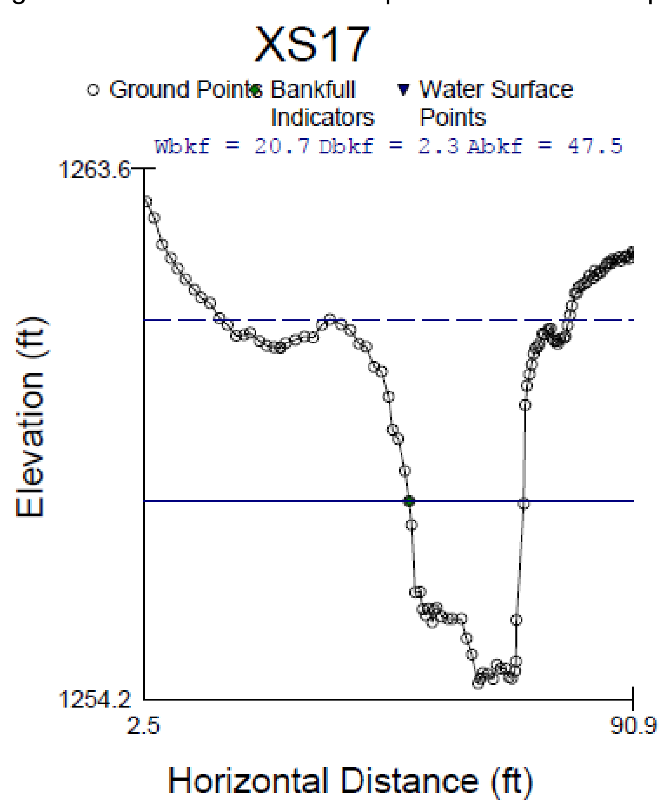


Figure C.18. Overall longitudinal profile from RIVERMorph.

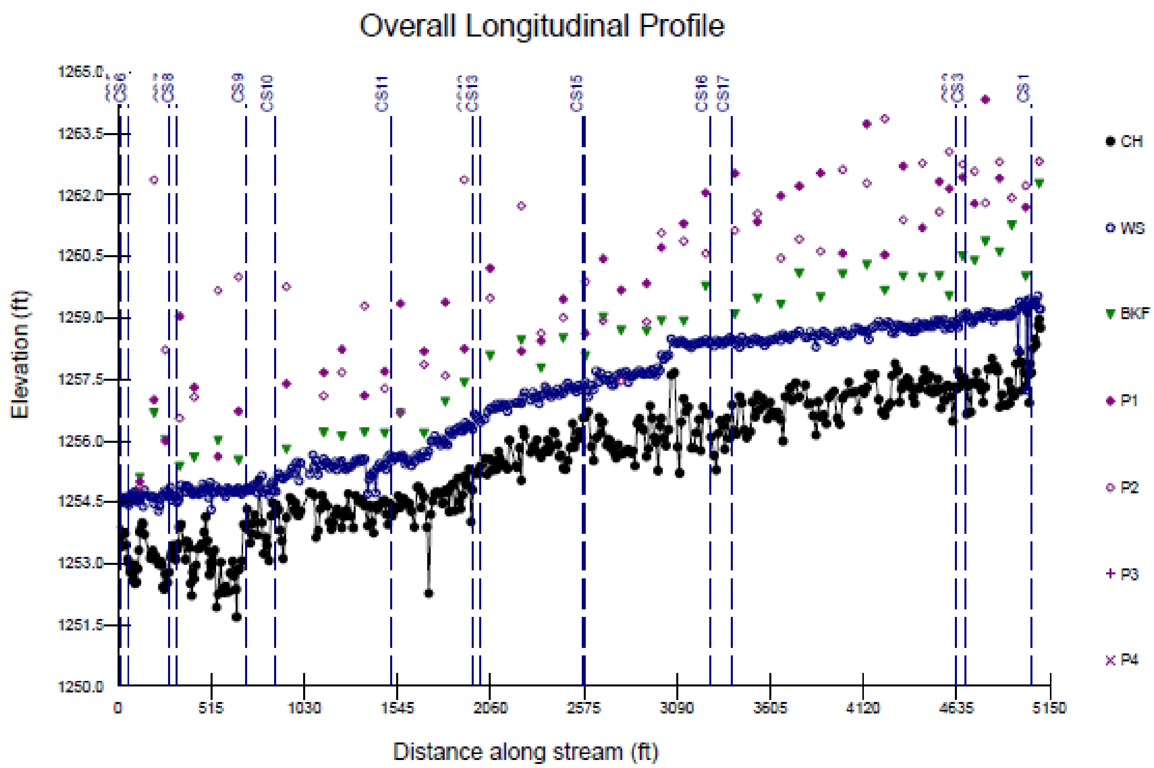


Figure C.19. Northern longitudinal profile from RIVERMorph.

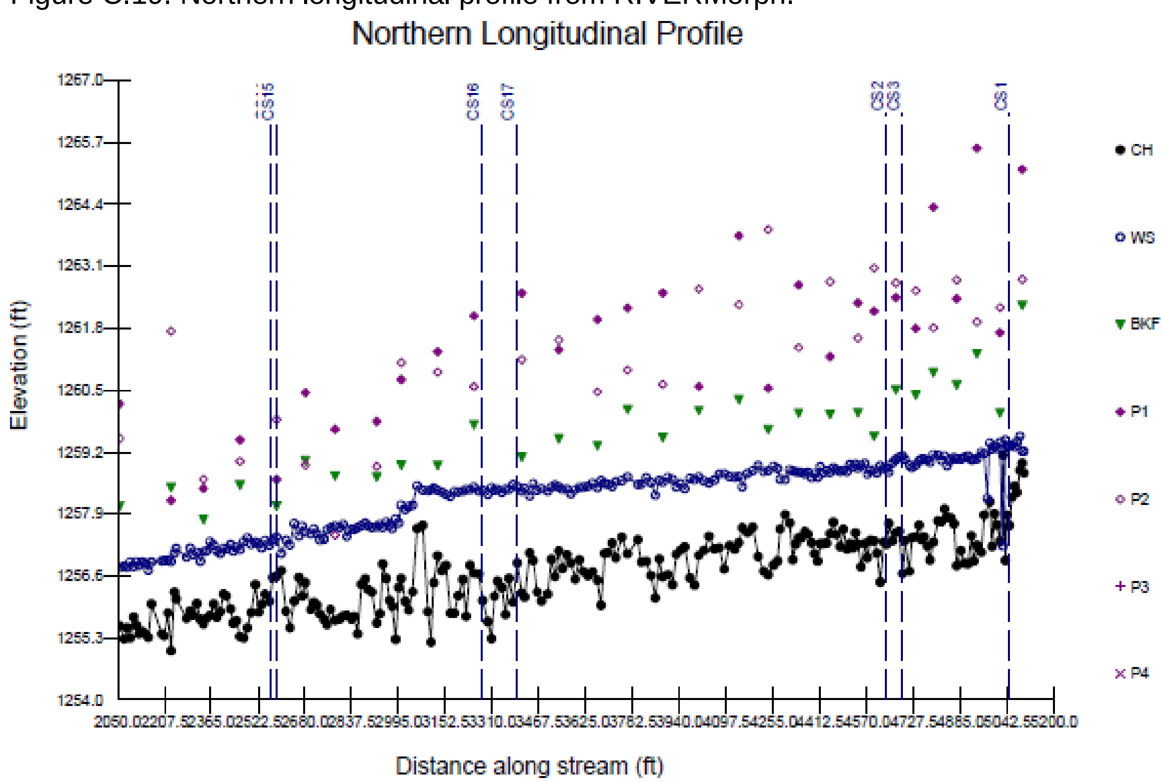


Figure C.20. Middle longitudinal profile from RIVERMorph.

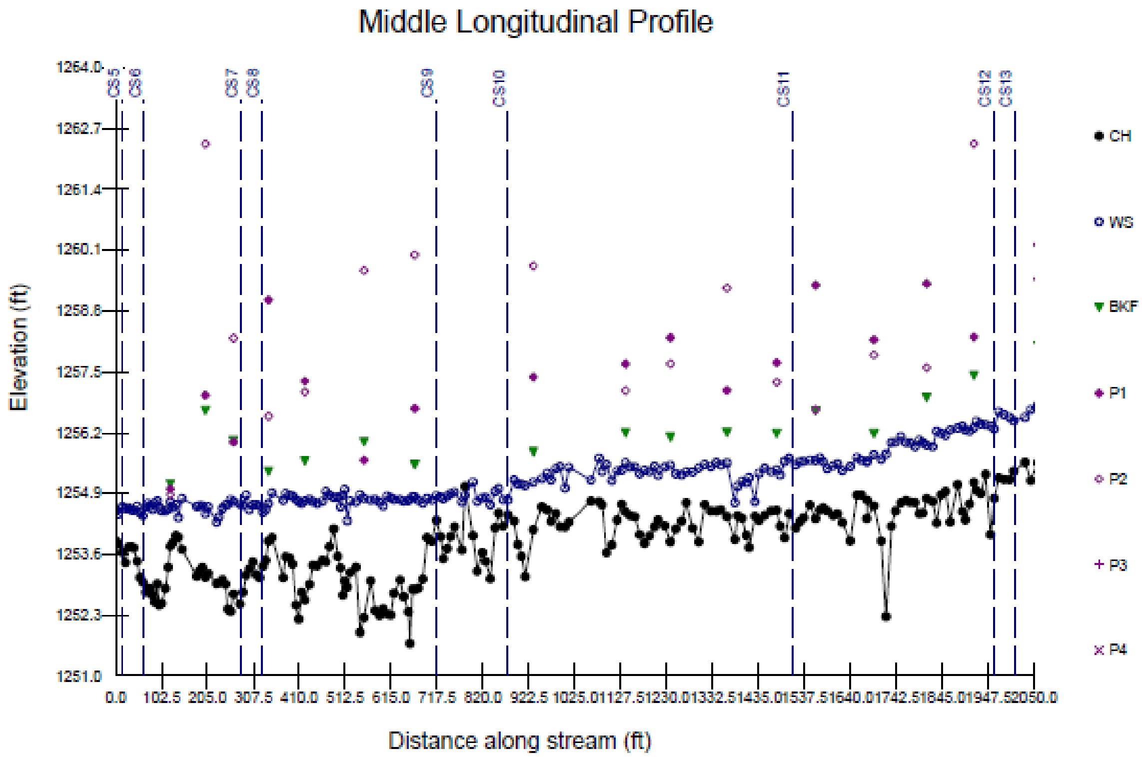


Figure C.21. Overall reach pebble count from RIVERMorph.

Data | Linear Graph | Bar Graph | Date: 07/26/2017

Size (mm)	TOT #	ITEM %	CUM %
0 - 0.062	167	18.72	18.72
0.062 - 0.125	155	17.38	36.10
0.125 - 0.25	141	15.81	51.91
0.25 - 0.50	133	14.91	66.82
0.50 - 1.0	88	9.87	76.68
1.0 - 2.0	49	5.49	82.17
2.0 - 4.0	28	3.14	85.31
4.0 - 5.7	36	4.04	89.35
5.7 - 8.0	10	1.12	90.47
8.0 - 11.3	9	1.01	91.48
11.3 - 16.0	20	2.24	93.72
16.0 - 22.6	10	1.12	94.84
22.6 - 32.0	16	1.79	96.64
32 - 45	10	1.12	97.76
45 - 64	4	0.45	98.21
64 - 90	3	0.34	98.54
90 - 128	2	0.22	98.77
128 - 180	4	0.45	99.22
180 - 256	3	0.34	99.55
256 - 362	1	0.11	99.66
362 - 512	3	0.34	100.00
512 - 1024	0	0.00	100.00
1024 - 2048	0	0.00	100.00
Bedrock	0	0.00	100.00

Particle Size Analysis

D16 (mm)	0.05
D35 (mm)	0.12
D50 (mm)	0.23
D84 (mm)	3.17
D95 (mm)	23.44
D100 (mm)	511.96
Silt/Clay (%)	18.72
Sand (%)	63.45
Gravel (%)	16.04
Cobble (%)	1.34
Boulder (%)	0.45
Bedrock (%)	0

Total Particles = 892

D 50 .2349 mm

Figure C.22. Overall riffle pebble count from RIVERMorph.

Data | Linear Graph | Bar Graph   Date: 07/26/2017

Size (mm)	TOT #	ITEM %	CUM %
0 - 0.062	91	10.38	10.38
0.062 - 0.125	110	12.54	22.92
0.125 - 0.25	128	14.60	37.51
0.25 - 0.50	169	19.27	56.78
0.50 - 1.0	119	13.57	70.35
1.0 - 2.0	92	10.49	80.84
2.0 - 4.0	27	3.08	83.92
4.0 - 5.7	30	3.42	87.34
5.7 - 8.0	27	3.08	90.42
8.0 - 11.3	30	3.42	93.84
11.3 - 16.0	21	2.39	96.24
16.0 - 22.6	19	2.17	98.40
22.6 - 32.0	7	0.80	99.20
32 - 45	4	0.46	99.66
45 - 64	2	0.23	99.89
64 - 90	1	0.11	100.00
90 - 128	0	0.00	100.00
128 - 180	0	0.00	100.00
180 - 256	0	0.00	100.00
256 - 362	0	0.00	100.00
362 - 512	0	0.00	100.00
512 - 1024	0	0.00	100.00
1024 - 2048	0	0.00	100.00
Bedrock	0	0.00	100.00

Particle Size Analysis

D16 (mm)	0.09
D35 (mm)	0.23
D50 (mm)	0.41
D84 (mm)	4.04
D95 (mm)	13.57
D100 (mm)	89.98
Silt/Clay (%)	10.38
Sand (%)	70.46
Gravel (%)	19.05
Cobble (%)	0.11
Boulder (%)	0
Bedrock (%)	0

Total Particles = 877

D 50   0.41 mm

Figure C.23. Meander belt width measurements.

Figure C.24. Meander wavelength measurements.

Figure C.25. Radius of curvature measurements.

Figure C.26. Sinuosity measurements.

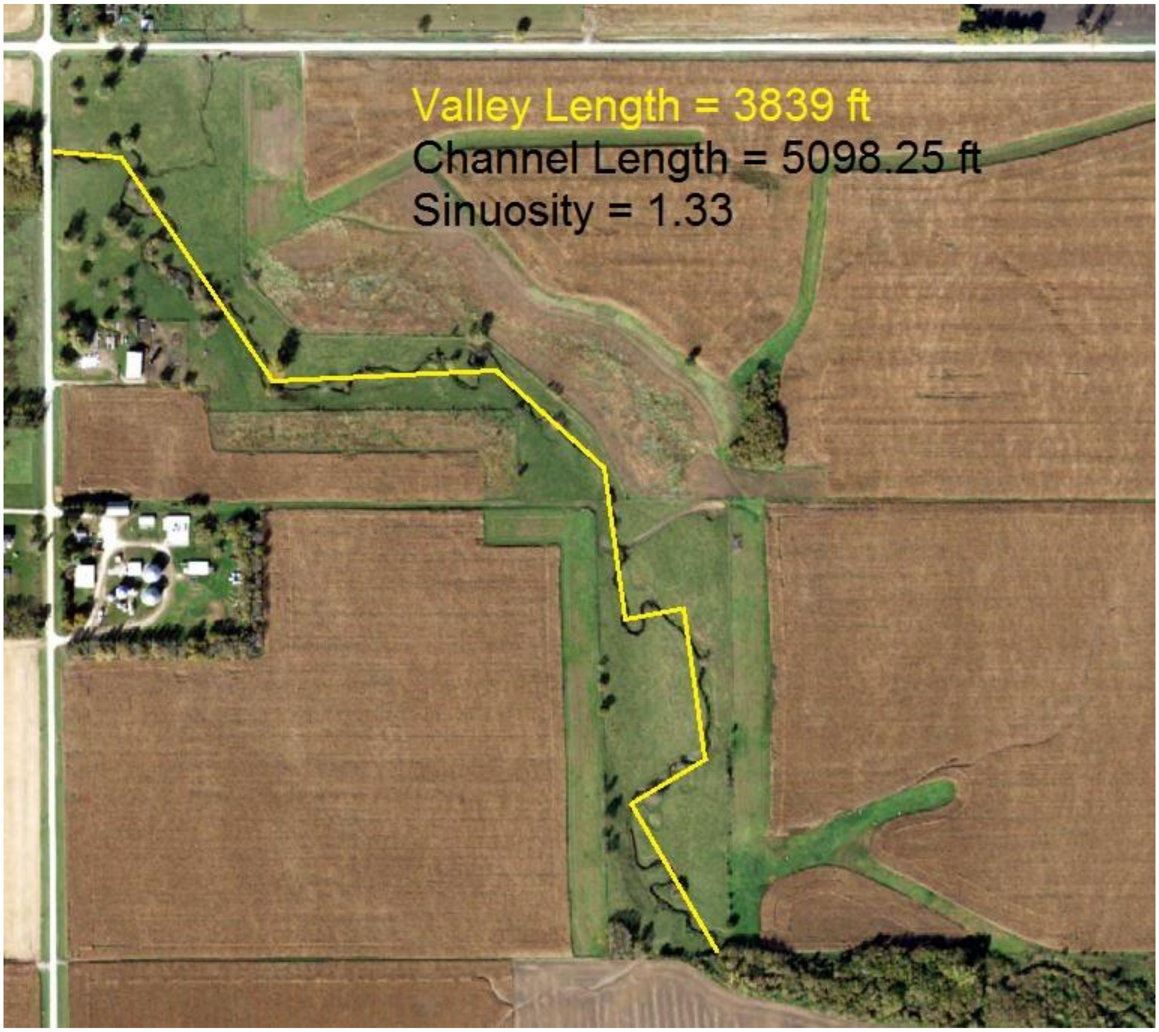


Figure C.27. Reference reach riffle cross-section 1 from RIVERMorph.

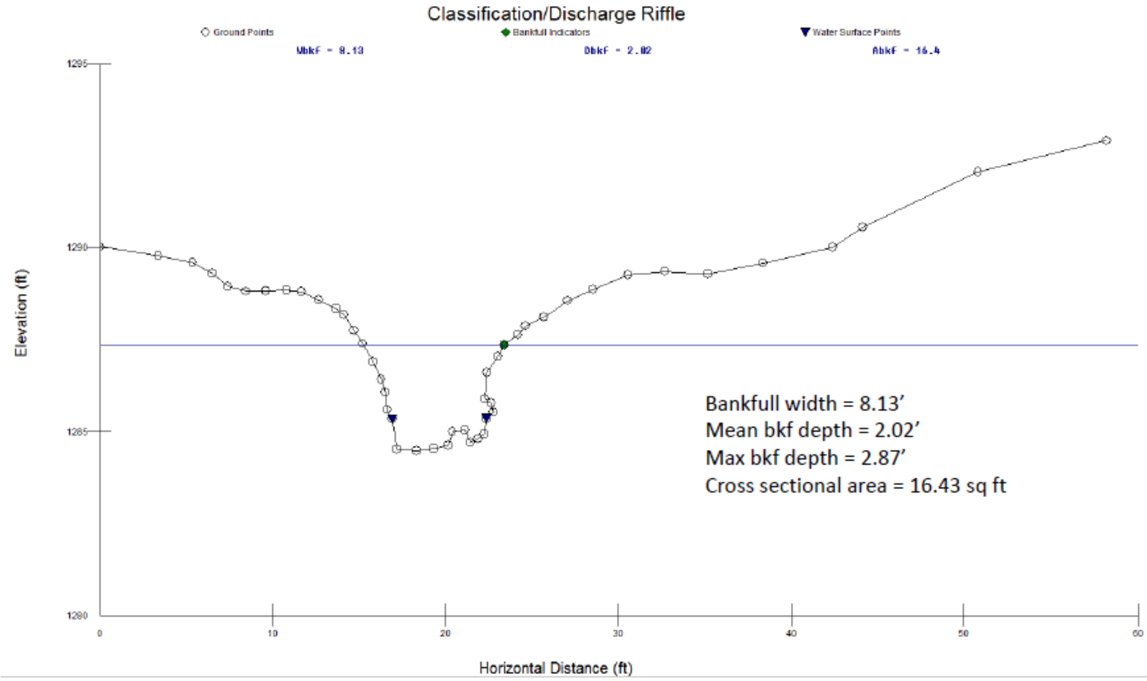


Figure C.28. Reference reach riffle cross-section 2 from RIVERMorph.

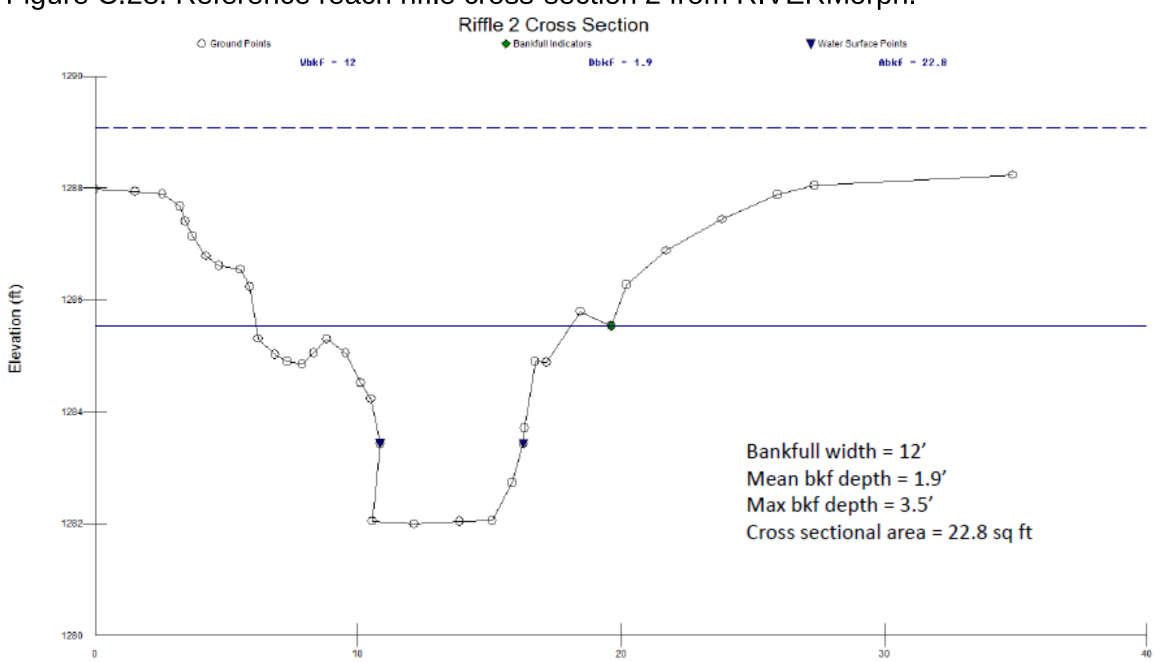


Figure C.29. Reference reach pool cross-section 3 from RIVERMorph.

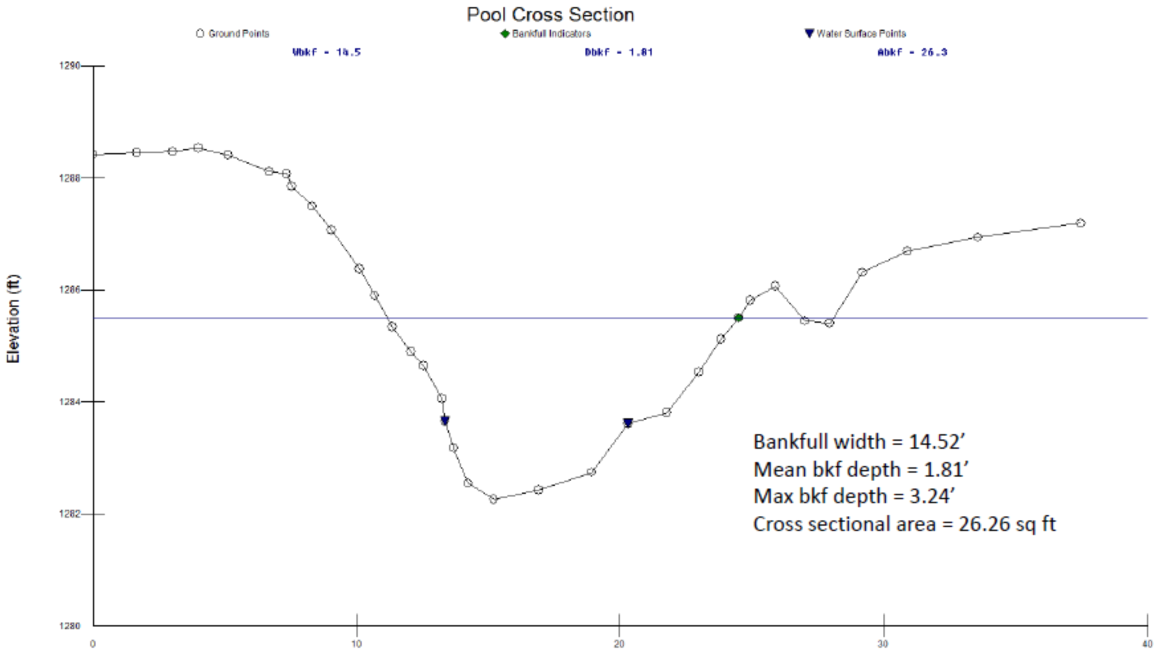


Figure C.30. Reference reach longitudinal profile from RIVERMorph.

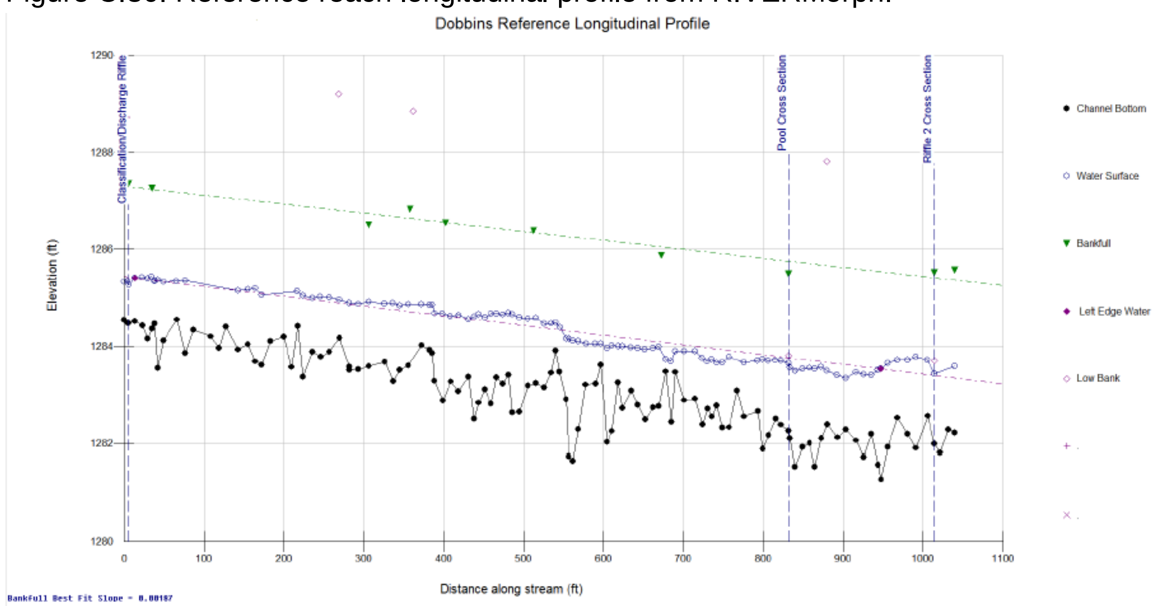


Figure C.31. Reference reach pebble count.

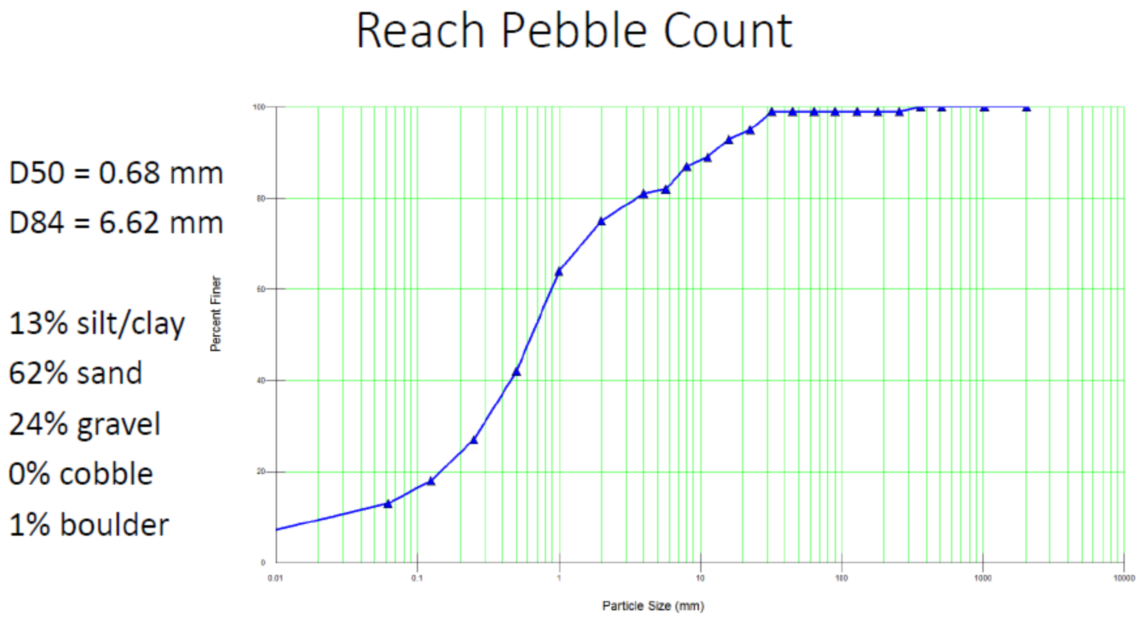


Figure C.32. Reference riffle pebble count.

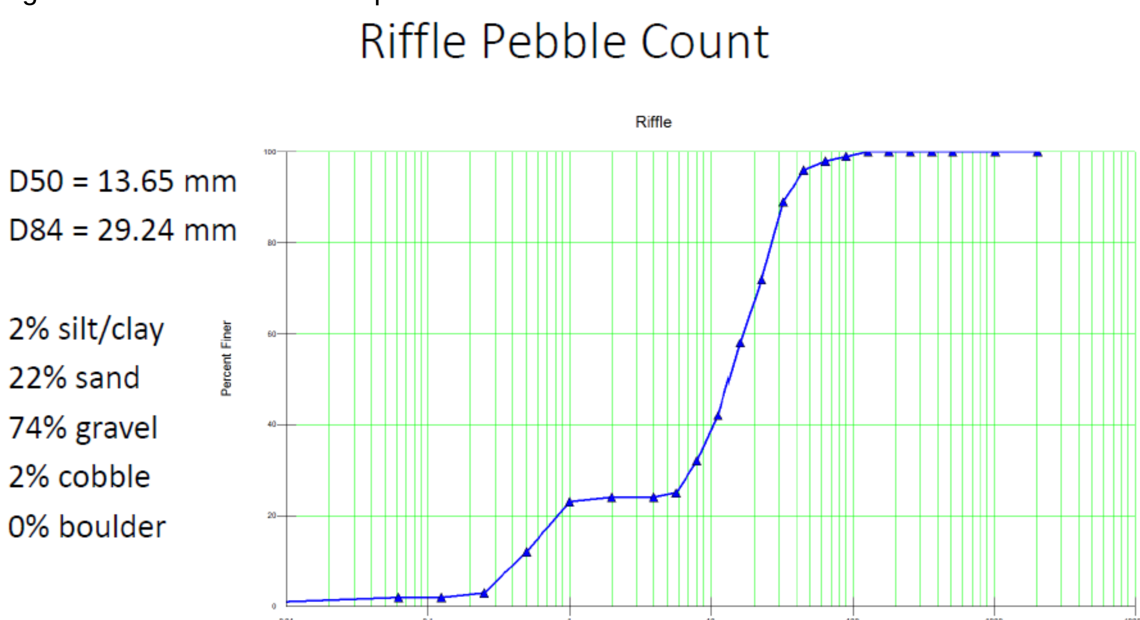


Table C.33. Dobbins geomorphological dataset part 1.

600th Ave + Reference		DA	BKF_W	Mean_BKF_D	Max_D	BKF_A	WDRatio	W_FPA	Ent_Ratio
XS1	Northern	9.95	24.2	1.79	3.56	43.43	13.52	176.66	7.3
XS3	Northern	9.95	15.43	2.36	3.87	36.35	6.54	94.91	6.15
XS2	Northern	9.95	24.52	1.57	2.87	38.55	15.62	77.94	3.18
XS17	Northern	9.95	20.67	2.3	3.22	47.45	8.99	62.8	3.04
XS16	Northern	9.95	21.29	2.39	4.69	50.87	8.91	75.13	3.53
XS15	Northern	9.95	17.29	2.78	4.25	48.08	6.22	56.82	3.29
XS14	Northern	9.95	24.21	2.04	4.28	49.49	11.87	66.6	2.75
XS13	Middle	9.95	23.35	2.01	3.41	47.01	11.62	71.43	3.059
XS12	Middle	9.95	30.46	1.42	4.08	43.37	21.45	139.65	4.585
XS11	Middle	9.95	11.43	1.81	3.01	20.71	6.31	44.87	3.926
XS10	Middle	9.95	15.12	2.97	4.74	44.93	5.09	125.75	8.317
XS9	Middle	9.95	14.03	1.96	3.42	27.44	7.16	69.29	4.939
XS8	Middle	9.95	20.56	2.02	4.18	41.49	10.18	95.25	4.633
XS7	Middle	9.95	13.37	2.63	3.85	35.23	5.08	52.16	3.901
XS6	Middle	9.95	17.09	2.97	4.21	50.68	5.75	76.39	4.47
XS5	Southern	9.95	13.49	2.58	3.43	34.76	5.23	40.3	2.987
XS18	Southern	9.95	26	1.87	2.64	48.72	13.9	30	1.15
Ref 1	Reference	5.65	8.13	2.02	2.87	16.43	4.024752	43.09	5.3
Ref 2	Reference	5.65	14.52	1.81	3.24	26.26	8.022099	43.09	5.3
Ref 3	Reference	5.65	12	1.9	3.5	22.8	6.315789	43.09	5.3
Average		9.31	18.358	2.16	3.666	38.703	9.090132	74.261	4.35535
Stdev		1.58	5.85704	0.444368268	0.6104	10.809	4.426907	37.1375	1.6618

Table C.34. Dobbins geomorphologic dataset part 2.

600th Ave + Reference		Hyd_Rad	WS_Slope	Valley_L	Channel_L	Sinuosity	ReachD50	ReachD84	RiffleD50	RiffleD84	BEHI_Rating
XS1	Northern	1.65	0.00031	432.8	653.5	1.51	0.55	2.36	0.34	1.12	38.7
XS3	Northern	2.01	0.00031	432.8	653.5	1.51	0.55	2.36	0.34	1.12	36.8
XS2	Northern	1.46	0.00031	432.8	653.5	1.51	0.55	2.36	0.34	1.12	33.3
XS17	Northern	1.98	0.00101	521.4	573.47	1.1	0.24	1.75	0.35	1.6	44.9
XS16	Northern	2.03	0.00101	521.4	573.47	1.1	0.24	1.75	0.35	1.6	37.7
XS15	Northern	2.32	0.00171	392.7	651.24	1.658	0.29	5.21	0.43	1.82	39.4
XS14	Northern	1.66	0.00123	484.2	543.47	1.122	0.24	5.93	6.97	15.29	36.9
XS13	Middle	1.73	0.00091	520.7	747.29	1.435	0.08	2.49	0.2	4.11	29.3
XS12	Middle	1.21	0.00091	520.7	747.29	1.435	0.08	2.49	0.2	4.11	29.3
XS11	Middle	1.09	0.00091	520.7	747.29	1.435	0.08	2.49	0.2	4.11	35.7
XS10	Middle	2.28	0.00017	552.6	606.94	1.098	0.24	0.77	0.23	0.69	38
XS9	Middle	1.46	0.00017	552.6	606.94	1.098	0.24	0.77	0.23	0.69	23.4
XS8	Middle	1.72	0.00061	394.7	726.04	1.839	0.15	6.71	0.94	7.08	36.6
XS7	Middle	2	0.00061	394.7	726.04	1.839	0.15	6.71	0.94	7.08	33.3
XS6	Middle	2.15	0.00061	394.7	726.04	1.839	0.15	6.71	0.94	7.08	27.4
XS5	Southern	1.97	0.00061	394.7	726.04	1.839	0.15	6.71	0.94	7.08	35.8
XS18	Southern	1.78	0.0015	587	605	1.031	0.33	24.48			26.2
Ref 1	Reference	1.350041	0.00201	605	1073	1.54	0.68	6.62	13.65	29.24	
Ref 2	Reference	1.44763	0.00201	605	1073	1.54	0.68	6.62	13.65	29.24	
Ref 3	Reference	1.443038	0.00201	605	1073	1.54	0.68	6.62	13.65	29.24	
Average		1.737035	0.0009465	493.31	724.303	1.4509	0.3175	5.0955	2.888947	8.074737	34.2764706
Stdev		0.350455	0.0006177	78.5214	163.30897	0.277229	0.213834	5.111836	5.019468	10.06705	5.53122154

Table C.35. Standardized Dobbins geomorphological dataset part 1.

600th Ave + Reference		DA	BKF_W	Mean_BKF_D	Max_D	BKF_A	WDRatio	W_FPA	Ent_Ratio
XS1	Northern	0.41	0.99743	-0.832642712	-0.174	0.4374	1.000669	2.7573	1.771965
XS3	Northern	0.41	-0.4999	0.450077142	0.3342	-0.218	-0.57605	0.55602	1.079944
XS2	Northern	0.41	1.05207	-1.327727568	-1.304	-0.014	1.475041	0.09906	-0.70728
XS17	Northern	0.41	0.39474	0.315053999	-0.731	0.8093	-0.02262	-0.3086	-0.79152
XS16	Northern	0.41	0.50059	0.517588713	1.6777	1.1257	-0.04069	0.0234	-0.49666
XS15	Northern	0.41	-0.1823	1.395239139	0.9568	0.8676	-0.64834	-0.4696	-0.64108
XS14	Northern	0.41	0.99914	-0.270046285	1.006	0.998	0.627948	-0.2063	-0.96603
XS13	Middle	0.41	0.85231	-0.337557856	-0.419	0.7686	0.571475	-0.0762	-0.78009
XS12	Middle	0.41	2.06623	-1.665285424	0.6783	0.4318	2.791987	1.76073	0.138194
XS11	Middle	0.41	-1.1828	-0.787634998	-1.075	-1.665	-0.62801	-0.7914	-0.25836
XS10	Middle	0.41	-0.5528	1.822812423	1.7596	0.5761	-0.9036	1.38644	2.383952
XS9	Middle	0.41	-0.7389	-0.450077142	-0.403	-1.042	-0.436	-0.1339	0.351216
XS8	Middle	0.41	0.37596	-0.315053999	0.8421	0.2579	0.246192	0.56517	0.167078
XS7	Middle	0.41	-0.8516	1.057681283	0.3015	-0.321	-0.90585	-0.5951	-0.27341
XS6	Middle	0.41	-0.2165	1.822812423	0.8913	1.1081	-0.75451	0.05733	0.068991
XS5	Southern	0.41	-0.8311	0.945161997	-0.387	-0.365	-0.87197	-0.9145	-0.82341
XS18	Southern	0.41	1.30475	-0.652611855	-1.681	0.9268	1.086507	-1.1918	-1.92884
Ref 1	Reference	-2.32	-1.7463	-0.315053999	-1.304	-2.061	-1.14423	-0.8393	0.56845
Ref 2	Reference	-2.32	-0.6553	-0.787634998	-0.698	-1.151	-0.24126	-0.8393	0.56845
Ref 3	Reference	-2.32	-1.0855	-0.585100284	-0.272	-1.471	-0.6267	-0.8393	0.56845
Avg (should be 0)		0	4.4E-16	-3.27516E-16	-5E-16	5E-16	-5E-16	1.9E-16	2.33E-16
Stdv (should be 1)		1	1	1	1	1	1	1	1

Table C.36. Standardized Dobbins geomorphological dataset part 2.

600th Ave + Reference		Hyd_Rad	WS_Slope	Valley_L	Channel_L	Sinuosity	ReachD50	ReachD84	RiffleD50	RiffleD84	BEHI_Rating
XS1	Northern	-0.24835	-1.030468	-0.77062	-0.433552	0.213181	1.087292	-0.53513	-0.50781	-0.69084	0.79973825
XS3	Northern	0.778886	-1.030468	-0.77062	-0.433552	0.213181	1.087292	-0.53513	-0.50781	-0.69084	0.45623365
XS2	Northern	-0.7905	-1.030468	-0.77062	-0.433552	0.213181	1.087292	-0.53513	-0.50781	-0.69084	-0.17653796
XS17	Northern	0.693283	0.102804	0.357737	-0.923605	-1.26574	-0.36243	-0.65446	-0.50582	-0.64316	1.92064797
XS16	Northern	0.835954	0.102804	0.357737	-0.923605	-1.26574	-0.36243	-0.65446	-0.50582	-0.64316	0.61894635
XS15	Northern	1.663449	1.2360759	-1.28131	-0.447391	0.747037	-0.1286	0.022399	-0.48988	-0.62131	0.92629257
XS14	Northern	-0.21982	0.4589751	-0.11602	-1.107306	-1.18638	-0.36243	0.163249	0.813045	0.71672	0.47431284
XS13	Middle	-0.02008	-0.059092	0.348822	0.1407577	-0.05735	-1.11067	-0.5097	-0.5357	-0.39383	-0.89970553
XS12	Middle	-1.50386	-0.059092	0.348822	0.1407577	-0.05735	-1.11067	-0.5097	-0.5357	-0.39383	-0.89970553
XS11	Middle	-1.84627	-0.059092	0.348822	0.1407577	-0.05735	-1.11067	-0.5097	-0.5357	-0.39383	0.25736257
XS10	Middle	1.549312	-1.257122	0.755081	-0.718656	-1.27296	-0.36243	-0.84617	-0.52973	-0.73355	0.67318392
XS9	Middle	-0.7905	-1.257122	0.755081	-0.718656	-1.27296	-0.36243	-0.84617	-0.52973	-0.73355	-1.96637768
XS8	Middle	-0.04861	-0.54478	-1.25584	0.0106363	1.399927	-0.78332	0.315836	-0.38828	-0.09881	0.42007528
XS7	Middle	0.750351	-0.54478	-1.25584	0.0106363	1.399927	-0.78332	0.315836	-0.38828	-0.09881	-0.17653796
XS6	Middle	1.178366	-0.54478	-1.25584	0.0106363	1.399927	-0.78332	0.315836	-0.38828	-0.09881	-1.24321012
XS5	Southern	0.664748	-0.54478	-1.25584	0.0106363	1.399927	-0.78332	0.315836	-0.38828	-0.09881	0.27544176
XS18	Southern	0.122596	0.8960943	1.193178	-0.730535	-1.51463	0.058457	3.792082			-1.46016039
Ref 1	Reference	-1.10426	1.7217639	1.422415	2.1351981	0.321395	1.69524	0.298229	2.143863	2.102429	
Ref 2	Reference	-0.8258	1.7217639	1.422415	2.1351981	0.321395	1.69524	0.298229	2.143863	2.102429	
Ref 3	Reference	-0.8389	1.7217639	1.422415	2.1351981	0.321395	1.69524	0.298229	2.143863	2.102429	
Avg (should be 0)		-6.8E-16	1.11E-16	-6.9E-16	-1.6E-15	1.38E-15	0	-2.8E-16	0	0	-8.6206E-16
Stdv (should be 1)		1	1	1	1	1	1	1	1	1	1

Appendix D: One-way ANOVA Analyses of the Overall Dataset

Table D.1. One-way ANOVA of Bankfull Width.

BKF Width		
CG	MG	NG
-0.70784	0.051098	2.004748
-0.91559	0.467727	1.690588
0.155818	-0.15159	0.208741
-0.24448		-0.09528
-0.59693		-0.79961
-0.80637		-1.10139
-0.40156		-0.74162
-0.76921		-0.8835
-0.19663		
-0.19606		
-0.58567		
-0.36046		
-0.39537		
-0.17861		
-0.69039		
1.689462		
2.415746		
2.134241		

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
CG	18	-0.64991	-0.03611	1.036436
MG	3	0.367239	0.122413	0.099701
NG	8	0.282671	0.035334	1.443253

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.078408	2	0.039204	0.036506	0.964202	3.369016
Within Groups	27.92159	26	1.073907			
Total	28	28				

p > 0.05, not statistically significant.

P higher than before

Table D.2. One-way ANOVA of Bankfull Area.

BKF Area		
CG	MG	NG
-0.28452	-0.5623	2.610944
-0.59776	-0.60022	1.466492
-0.3047	-0.58108	-0.58858
-0.25762		-0.02904
-0.21016		-0.50088
-0.40997		-0.23551
-0.32901		-0.41605
-0.51072		-0.65312
-0.30392		-0.52598
-0.22555		-0.57073
-0.24378		
-0.2077		
-0.25193		
-0.36704		
-0.39549		
1.891733		
2.358489		
-0.76955		
-0.31851		
2.923796		

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
CG	20	1.186061	0.059303	1.057488
MG	3	-1.7436	-0.5812	0.000359
NG	10	0.557542	0.055754	1.199135

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.114805	2	0.557403	0.541427	0.587497	3.31583
Within Groups	30.88519	30	1.029506			
Total	32	32				

p > 0.05, not statistically significant.

P higher than before

Table D.3. One-way ANOVA of Width-depth Ratio.

WD Ratio		
CG	MG	NG
-1.25214	1.862736	0.688956
-1.01025	0.573957	1.402741
1.991614	-0.02086	-0.5562
0.042583		-0.39758
-1.12128		0.276546
-1.25413		0.494647
-0.24293		-1.22439
-0.84172		-1.46336
0.419303		-0.67079
0.092151		-1.0091
-1.0281		
-0.49474		
-0.47888		
0.835678		
-0.96465		
0.831713		
1.7061		
1.109296		
1.049814		
0.653266		

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
CG	20	0.042702	0.002135	1.045292
MG	3	2.415828	0.805276	0.92712
NG	10	-2.45853	-0.24585	0.859475

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2.549937	2	1.274969	1.298777	0.287769	3.31583
Within Groups	29.45006	30	0.981669			
Total	32	32				

$p > 0.05$, not statistically significant.

P higher than before

Table D.4. One-way ANOVA of Entrenchment Ratio.

Entrenchment Ratio		
CG	MG	NG
1.268322	1.194466	0.771394
-0.63769	1.03426	0.846754
-0.35164	2.396475	1.860626
-1.01403		-1.84267
-0.40155		-1.04528
-0.64854		-0.04127
-0.3308		-0.04127
-0.19797		-0.04127
0.82687		
-1.14816		
-0.91376		
-0.80958		
-1.02228		
-0.96151		
0.327687		
-0.23544		
0.191256		
0.96662		

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
CG	18	-5.0922	-0.2829	0.532514
MG	3	4.625201	1.541734	0.554354
NG	8	0.466994	0.058374	1.319983

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	8.59867	2	4.299335	5.7616	0.008487	3.369016
Within Groups	19.40133	26	0.746205			
Total	28	28				

$p < 0.05$, statistically significant.

P higher than before

Table D.4.1. Games-Howell Post-Hoc Test of Entrenchment Ratio.

Games-Howell				3 groups	If q > qcrit, sig diff
Ent Ratio	**std error**	**adj df**	**q score**	**q crit**	**Result**
CG v MG	0.258789462	4.25173	-7.050648	5.04	Sig diff
CG v NG	0.353059772	8.203034	-0.966618	4.04	Not sig diff
MG v NG	0.45971002	2.584225	3.226729	8.33	Not sig diff

Table D.5. One-way ANOVA of Slope.

Slope		
CG	MG	NG
-0.74385	2.714643	-0.76899
-0.47809	2.247765	-0.76899
-0.47809	-0.08663	0.272509
-0.47809		2.247765
-0.58583		1.421749
-0.58583		-0.2662
-0.58583		-0.58583
-0.74385		-0.08304
-0.69357		-0.08304
-0.36316		-0.08304
-0.19078		
-0.44217		
-0.44217		
-0.69357		
-0.69357		
-0.40985		
-0.33802		
1.278094		
1.960455		
-0.47091		

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
CG	20	-6.17869	-0.30893	0.468234
MG	3	4.87578	1.62526	2.252415
NG	10	1.302907	0.130291	0.955083

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	10.00297	2	5.001487	6.821131	0.003616	3.31583
Within Groups	21.99703	30	0.733234			
Total	32	32				

p < 0.05, statistically significant.

P higher than before

Table D.5.1. Games-Howell Post-Hoc Test of Slope.

Games-Howell				3 groups	If q > qcrit, sig diff
Slope	**std error**	**adj df**	**q score**	**q crit**	**Result**
CG v MG	0.925485877	2.006856	-2.089923	8.33	Not sig diff
CG v NG	0.237847371	12.84256	-1.846667	3.77	Not sig diff
MG v NG	1.317851709	2.007645	1.134399	8.33	Not sig diff

Table D.6. One-way ANOVA of Sinuosity.

Sinuosity		
CG	MG	NG
-0.13644	-1.20056	-0.76575
0.496424	-1.06697	-0.76575
-0.90948	-0.87379	-0.83628
1.032695		-1.23921
-0.98919		1.68854
-0.98919		0.605127
0.496424		0.605127
0.496424		0.605127
-0.99644		
0.224664		
0.224664		
0.224664		
1.68854		
1.68854		
1.68854		
-0.99644		

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
CG	16	3.244392	0.202774	0.976092
MG	3	-3.14132	-1.04711	0.026991
NG	8	-0.10307	-0.01288	1.050876

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3.948514	2	1.974257	2.148706	0.13854	3.402826
Within Groups	22.05149	24	0.918812			
Total	26	26				

$F(2, 24) = 2.149$, $p = 0.1385$

$p > 0.05$, not statistically significant.

Table D.7. One-way ANOVA of Reach D50.

Reach D50		
CG	MG	NG
-0.32643	-0.39807	-0.29038
-0.39852	-0.29939	-0.29038
-0.39852	-0.39988	3.620795
-0.39852		-0.40664
-0.36698		3.620795
-0.36698		-0.28588
-0.36698		-0.36698
-0.32643		-0.12817
-0.18674		-0.12817
-0.32643		-0.12817
-0.3039		
-0.32643		
-0.32643		
-0.18674		
-0.18674		
1.367813		
-0.40664		
-0.34896		
0.061084		

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
CG	19	-4.11949	-0.21682	0.159936
MG	3	-1.09734	-0.36578	0.003306
NG	10	5.216835	0.521684	2.677605

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4.016093	2	2.008047	2.158077	0.133744	3.327654
Within Groups	26.98391	29	0.93048			
Total	31	31				

$p > 0.05$, not statistically significant. Still ran games howell for CG vs MG

P much lower than before

Table D.7.1. Games-Howell Post-Hoc Test of Reach D50.

Games-Howell				3 groups	If q > qcrit, sig diff
Reach D50	**std error**	**adj df**	**q score**	**q crit**	**Result**
CG v MG	0.036716631	18	4.057168	3.61	Sig diff
CG v NG	0.599853987	9.011771	-1.231131	3.95	Not sig diff
MG v NG	0.598733798	8.999777	-1.482235	3.95	Not sig diff

Table D.8. One-way ANOVA of Reach D84.

Reach D84		
CG	MG	NG
-0.86872	1.78527	-0.45532
-0.68779	0.312584	-0.45532
-0.68779	-0.80245	1.680079
-0.68779		-0.92868
-0.24388		1.680079
-0.24388		1.625379
-0.24388		-0.24388
-0.86872		-0.25335
-0.70147		-0.25335
-0.32593		-0.25335
-0.40167		
-0.76563		
-0.76563		
-0.70147		
-0.70147		
1.364503		
0.417776		
0.733352		
2.942381		

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
CG	19	-3.4377	-0.18093	0.92405
MG	3	1.295405	0.431802	1.684733
NG	10	2.142298	0.21423	1.039705

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.640292	2	0.820146	0.810098	0.454627	3.327654
Within Groups	29.35971	29	1.012404			
Total	31	31				

p > 0.05, not statistically significant.

P higher than before

Table D.9. One-way ANOVA of BEHI Rating.

BEHI Rating		
CG	MG	NG
0.298754	0.298754	-0.612
0.911442	-0.86038	-1.93673
0.613378	-1.52275	1.292302
1.027356		-1.15845
0.745851		0.431227
1.938108		
0.017249		
0.596818		
0.795528		
0.414668		
-0.64512		
-0.64512		
-0.95974		
0.017249		
0.5637		
-1.6221		

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
CG	16	4.068025	0.254252	0.766264
MG	3	-2.08438	-0.69479	0.850034
NG	5	-1.98365	-0.39673	1.634123

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3.269485	2	1.634742	1.739924	0.199899	3.4668
Within Groups	19.73052	21	0.939548			
Total	23	23				

$F(2, 21) = 1.74$, $p = 0.2$

p > 0.05, not statistically significant.

Appendix E: One-way ANOVA Analyses of the Dobbins Dataset

Table E.1. One-way ANOVA of Bankfull Width.

BKF W			
N (CG)	M (CG)	S (NGw)	C (NGg)
0.99743208	0.85230759	-0.83113649	-1.746274453
-0.49991118	2.06623127	1.304754534	-0.655279757
1.05206719	-1.18284996		-1.085531186
0.39473861	-0.55283894		
0.50059412	-0.73893976		
-0.18234465	0.3759578		
0.99913943	-0.85162466		
	-0.21649159		

Anova: Single Factor

F(3, 16) = 2.282, p = 0.1183

p > 0.05, not statistically significant.

F < Fcrit

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*	
N (CG)	7	3.261716	0.465959	0.37829	*Widest*
M (CG)	8	-0.24825	-0.03103	1.164616	*Narrower*
S (NGw)	2	0.473618	0.236809	2.281015	*Wider*
C (NGg)	3	-3.48709	-1.16236	0.301995	*Narrowest*

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5.692942	3	1.897647	2.281673	0.118283	3.238872
Within Groups	13.30706	16	0.831691			
Total	19	19				

Table E.2. One-way ANOVA of Width-depth Ratio.

WD Ratio			
N (CG)	M (CG)	S (NGw)	C (NGg)
1.000669	0.571475	-0.87197	-1.14423
-0.57605	2.791987	1.086507	-0.24126
1.475041	-0.62801		-0.6267
-0.02262	-0.9036		
-0.04069	-0.436		
-0.64834	0.246192		
0.627948	-0.90585		
	-0.75451		

Anova: Single Factor

F(3, 16) = 0.5732, p = 0.6408

p > 0.05, not statistically significant.

F < Fcrit

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*	
N (CG)	7	1.815957	0.259422	0.642441	*Most stress/erosion*
M (CG)	8	-0.01831	-0.00229	1.567596	*Less stress/erosion*
S (NGw)	2	0.214537	0.107269	1.917818	*More stress/erosion*
C (NGg)	3	-2.01218	-0.67073	0.205291	*Least stress/erosion*

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.843784061	3	0.614595	0.573175	0.640815	3.238872
Within Groups	17.15621594	16	1.072263			
Total	19	19				

Table E.3. One-way ANOVA of Flood-prone Area Width.

W FPA			
N (CG)	M (CG)	S (NGw)	C (NGg)
2.757295	-0.07623	-0.91447	-0.83934
0.556015	1.760728	-1.19181	-0.83934
0.099064	-0.79141		-0.83934
-0.30861	1.386443		
0.0234	-0.13385		
-0.46963	0.56517		
-0.20629	-0.59511		
	0.057328		

Anova: Single Factor

F(3, 16) = 2.332, p = 0.113

p > 0.05, not statistically significant.

F < Fcrit

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
N (CG)	7	2.451243	0.350178	1.237028
M (CG)	8	2.173061	0.271633	0.822719
S (NGw)	2	-2.10628	-1.05314	0.038461
C (NGg)	3	-2.51802	-0.83934	1.85E-32

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5.780334136	3	1.926778	2.332014	0.11283	3.238872
Within Groups	13.21966586	16	0.826229			
Total	19	19				

Table E.4. One-way ANOVA of Entrenchment Ratio.

Ent Ratio				Anova: Single Factor			F(3, 16) = 2.032, p = 0.15			
N (CG)	M (CG)	S (NGw)	C (NGg)				p > 0.05, not statistically significant.			
1.77196459	-0.78008806	-0.82341458	0.56845002	SUMMARY			F < Fcrit			
1.07994371	0.13819356	-1.92884272	0.56845002	*Groups*	*Count*	*Sum*	*Average*	*Variance*		
-0.70727543	-0.25836449		0.56845002	N (CG)	7	-0.75066	-0.10724	1.157209	*More entrenched*	
-0.79152145	2.38395175			M (CG)	8	1.797569	0.224696	0.886355	*Less entrenched*	
-0.49666038	0.35121564			S (NGw)	2	-2.75226	-1.37613	0.610986	*Most entrenched*	
-0.64108212	0.16707791			C (NGg)	3	1.70535	0.56845	0	*Least entrenched*	
-0.96603106	-0.27340842									
	0.06899147									
				ANOVA						
				Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
				Between Groups	5.241272	3	1.747091	2.031689	0.149988	3.238872
				Within Groups	13.75873	16	0.85992			
				Total	19	19				

Table E.5. One-way ANOVA of Slope.

Slope				Anova: Single Factor			F(3, 16) = 8.172, p = 0.0016			
N (CG)	M (CG)	S (NGw)	C (NGg)				p < 0.05, statistically significant.			
-1.03047	-0.05909	-0.54478	1.721764	SUMMARY			F > Fcrit			
-1.03047	-0.05909	0.896094	1.721764	*Groups*	*Count*	*Sum*	*Average*	*Variance*		
-1.03047	-0.05909		1.721764	N (CG)	7	-1.19075	-0.17011	0.790453	*Flatter slope*	
0.102804	-1.25712			M (CG)	8	-4.32586	-0.54073	0.246059	*Flattest slope*	
0.102804	-1.25712			S (NGw)	2	0.351314	0.175657	1.038059	*Steeper slope*	
1.236076	-0.54478			C (NGg)	3	5.165292	1.721764	7.4E-32	*Steepest slope*	
0.458975	-0.54478									
	-0.54478									
				ANOVA						
				Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
				Between Groups	11.49681116	3	3.83227	8.172036	0.00159	3.238872
				Within Groups	7.503188839	16	0.468949			
				Total	19	19				

Table E.5.1. Games-Howell Post-Hoc Test of Slope.

Games-Howell				4 groups	If q > qcrit, sig diff
Slope	**std error**	**adj df**	**q score**	**q crit**	**Result**
N v M	0.30503	6.00055	1.215047	4.9	Not sig diff
N v S	0.598875	1.243747	-0.57736	32.82	Not sig diff
N v C	0.298763	6	-6.33234	4.9	Sig diff
M v S	0.52627	1.022264	-1.36126	32.82	Not sig diff
M v C	0.086995	7	-26.0072	4.68	Sig diff
S v C	0.734019	1	-2.10636	32.82	Not sig diff

Table E.6. One-way ANOVA of Reach D50.

Reach D50			
N (CG)	M (CG)	S (NGw)	C (NGg)
1.08729177	-1.11067439	-0.78331773	1.695239854
1.08729177	-1.11067439	0.058456547	1.695239854
1.08729177	-1.11067439		1.695239854
-0.36243059	-0.36243059		
-0.36243059	-0.36243059		
-0.1286044	-0.78331773		
-0.36243059	-0.78331773		
	-0.78331773		

Anova: Single Factor

F(3, 16) = 17.77, p = 0.000024

p < 0.05, statistically significant.

F > Fcrit

SUMMARY

Groups	Count	Sum	Average	Variance	
N (CG)	7	2.045979	0.292283	0.559869	*Larger particles*
M (CG)	8	-6.40684	-0.80085	0.096188	*Smallest particles*
S (NGw)	2	-0.72486	-0.36243	0.354292	*Smaller particles*
C (NGg)	3	5.08572	1.69524	0	*Largest particles*

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	14.61318	3	4.871059	17.76615	2.4E-05	3.238872
Within Groups	4.386823	16	0.274176			
Total	19	19				

Table E.6.1. Games-Howell Post-Hoc Test of Reach D50.

Games-Howell				4 groups	If q > qcrit, sig diff
D50	**std error**	**adj df**	**q score**	**q crit**	**Result**
N v M	0.212972	6.000026	5.132764	5.22	Not sig diff
N v S	0.27597	4.272699	2.372403	9.8	Not sig diff
N v C	0.211611	6	-6.6299	4.9	Sig diff
M v S	0.180381	1.241534	-2.43055	32.82	Not sig diff
M v C	0.034008	7	-73.3979	4.68	Sig diff
S v C	0.250522	1	-8.21352	32.82	Not sig diff

Table E.7. One-way ANOVA of Reach D84.

Reach D84			
N (CG)	M (CG)	S (NGw)	C (NGg)
-0.53513	-0.5097	0.315836	0.298229
-0.53513	-0.5097	3.792082	0.298229
-0.53513	-0.5097		0.298229
-0.65446	-0.84617		
-0.65446	-0.84617		
0.022399	0.315836		
0.163249	0.315836		
	0.315836		

Anova: Single Factor

F(3, 16) = 6.47, p = 0.0045

p < 0.05, statistically significant.

F > Fcrit

SUMMARY

Groups	Count	Sum	Average	Variance	
N (CG)	7	-2.72867	-0.38981	0.113204	*Smallest particles*
M (CG)	8	-2.27394	-0.28424	0.26633	*Smaller particles*
S (NGw)	2	4.107917	2.053959	6.042143	*Largest particle**
C (NGg)	3	0.894688	0.298229	0	*Larger particles*

** Due to placed riprap*

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	10.41432495	3	3.471442	6.469272	0.004486	3.238872
Within Groups	8.585675053	16	0.536605			
Total	19	19				

Table E.7.1. Games-Howell Post-Hoc Test of Reach D84

Games-Howell				4 groups	If q > qcrit, sig diff
D84	**std error**	**adj df**	**q score**	**q crit**	**Result**
N v M	0.079145	6.0355	-1.33384	4.9	Not sig diff
N v S	3.021375	1.000005	-0.80883	32.82	Not sig diff
N v C	0.042787	6	-16.0805	4.9	Sig diff
M v S	3.022539	1.000023	-0.77359	32.82	Not sig diff
M v C	0.094162	7	-6.18587	4.68	Sig diff
S v C	4.272441	1	0.410943	32.82	Not sig diff

Table E.8. One-way ANOVA of BEHI Rating.

BEHI Rating				Anova: Single Factor			F(2, 14) = 4.36, p = 0.0338			
N (CG)	M (CG)	S (NGw)	C (NGg)				p < 0.05, statistically significant.			
0.79973825	-0.89970553	0.275441763		SUMMARY			F > Fcrit			
0.45623365	-0.89970553	-1.46016039		*Groups*	*Count*	*Sum*	*Average*	*Variance*		
-0.17653796	0.25736257			N (CG)	7	5.019634	0.717091	0.405723		
1.92064797	0.67318392			M (CG)	8	-3.83492	-0.47936	0.845696		
0.61894635	-1.96637768			S (NGw)	2	-1.18472	-0.59236	1.506157		
0.92629257	0.42007528									
0.47431284	-0.17653796									
	-1.24321012			ANOVA						
				Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
				Between Groups	6.139633	2	3.069816	4.358603	0.033761	3.738892
				Within Groups	9.860367	14	0.704312			
				Total	16	16				

Table E.8.1. Games-Howell Post-Hoc Test of BEHI Rating.

Games-Howell				3 groups	If q > qcrit, sig diff
BEHI	**std error**	**adj df**	**q score**	**q crit**	**Result**
N v M	0.261182	6.225598	4.580926	4.34	Sig diff
N v S	0.768533	1.015186	1.70383	26.98	Not sig diff
M v S	0.810264	1.058977	0.139454	26.98	Not sig diff

Appendix F: Sugarloaf Creek Data and Analysis

Figure F.1. Site A longitudinal profile.

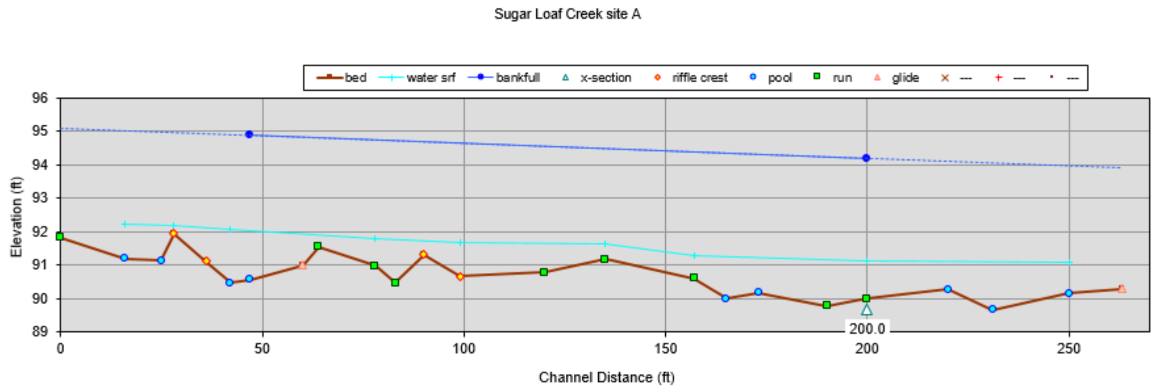


Figure F.2. Site A riffle cross-section plot.

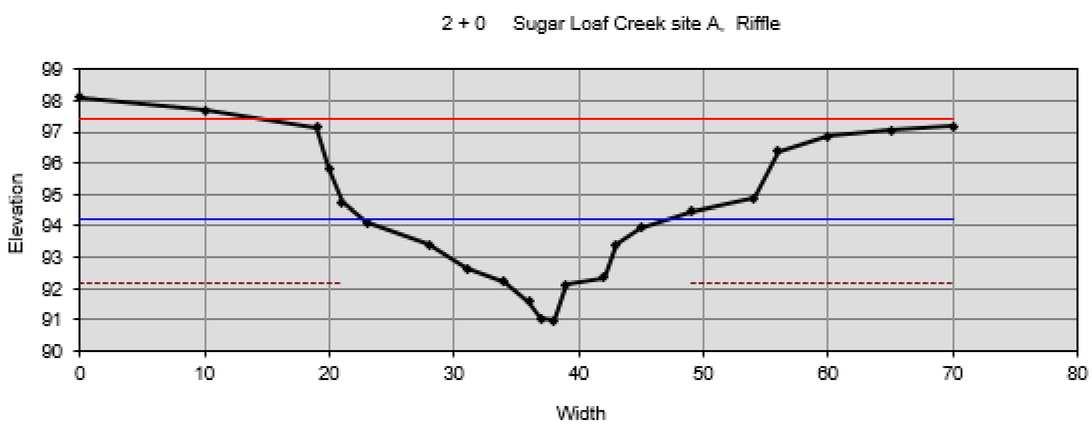
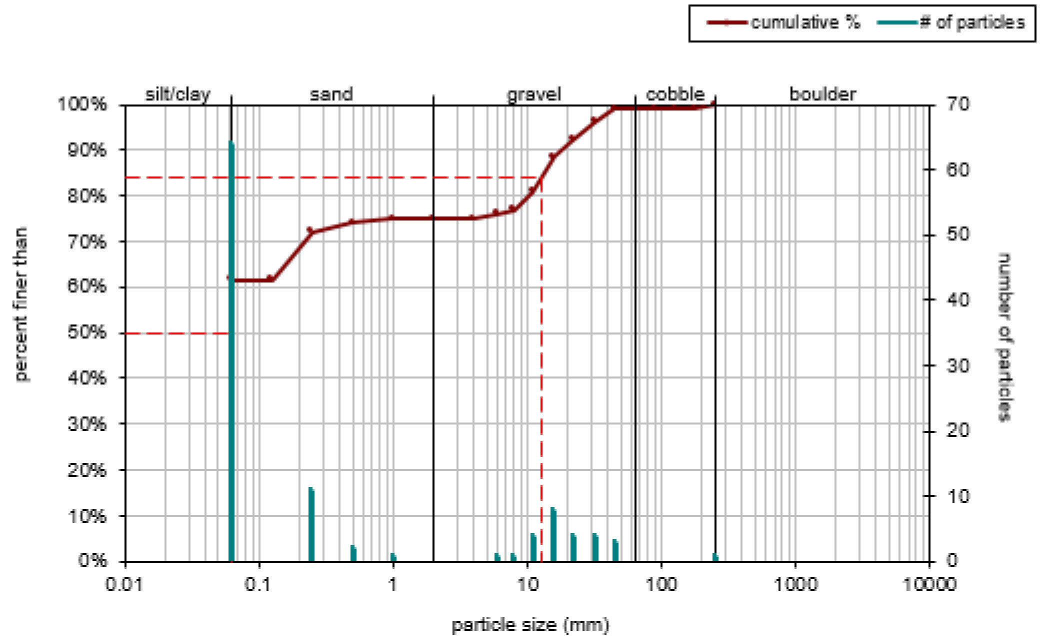


Figure F.3. Site A riffle pebble count.

Riffle Surface Pebble Count, Sugar Loaf Creek site A



Size (mm)	
D16	0.062
D35	0.062
D50	0.062
D65	0.16
D84	13
D95	29

Size Distribution	
mean	0.9
dispersion	105.3
skewness	0.76

Type	
silt/clay	62%
sand	13%
gravel	24%
cobble	1%
boulder	0%

Figure F.4. Site B longitudinal profile.

Sugar Loaf Creek site B

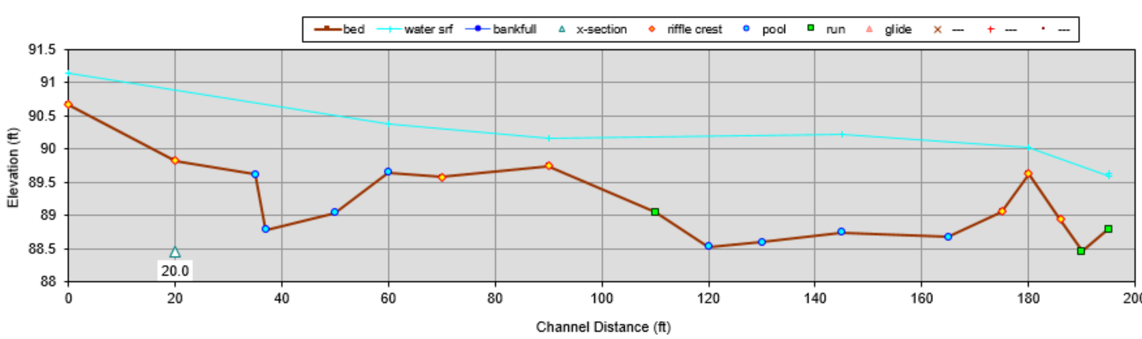


Figure F.5. Site B riffle cross-section plot.

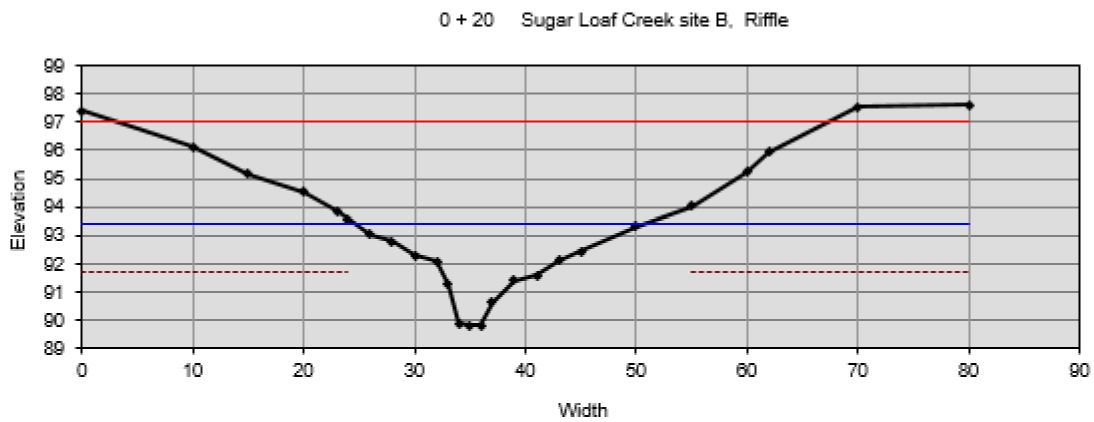
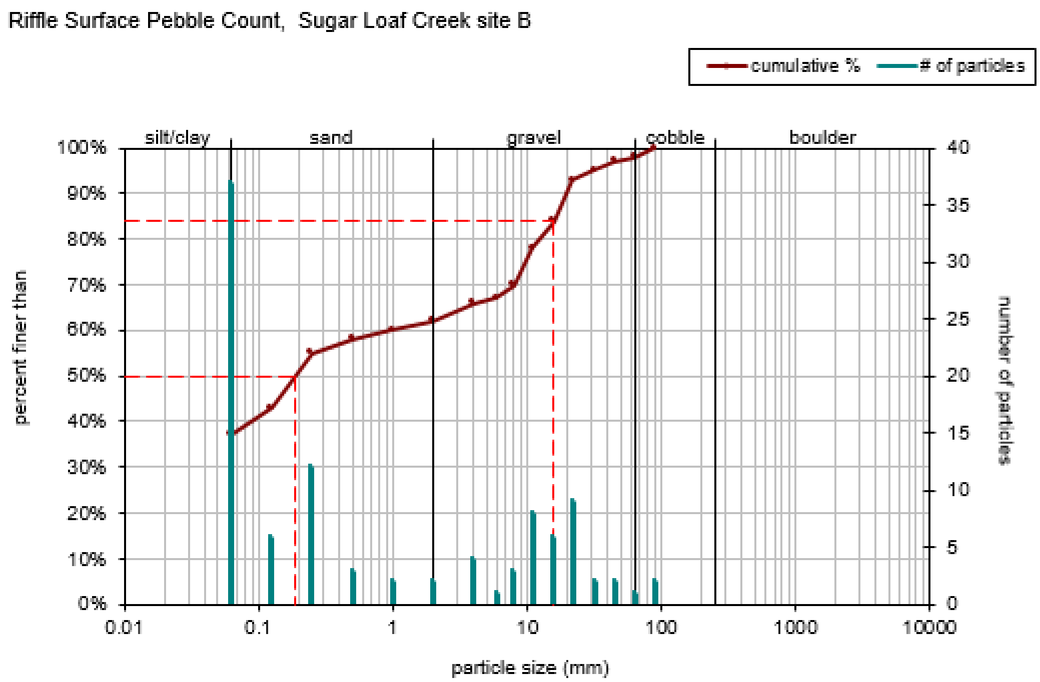


Figure F.6. Site B riffle pebble count.



Size (mm)	
D16	0.062
D35	0.062
D50	0.19
D65	3.4
D84	16
D95	32

Size Distribution	
mean	1.0
dispersion	43.6
skewness	0.46

Type	
silt/clay	37%
sand	25%
gravel	36%
cobble	2%
boulder	0%

Figure F.7. Site C/D longitudinal profile.

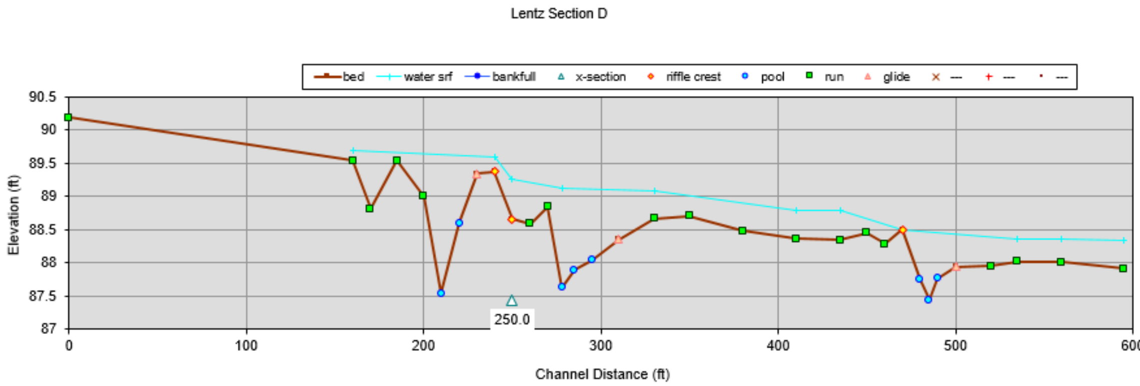


Figure F.8. Site C/D riffle cross-section plot.

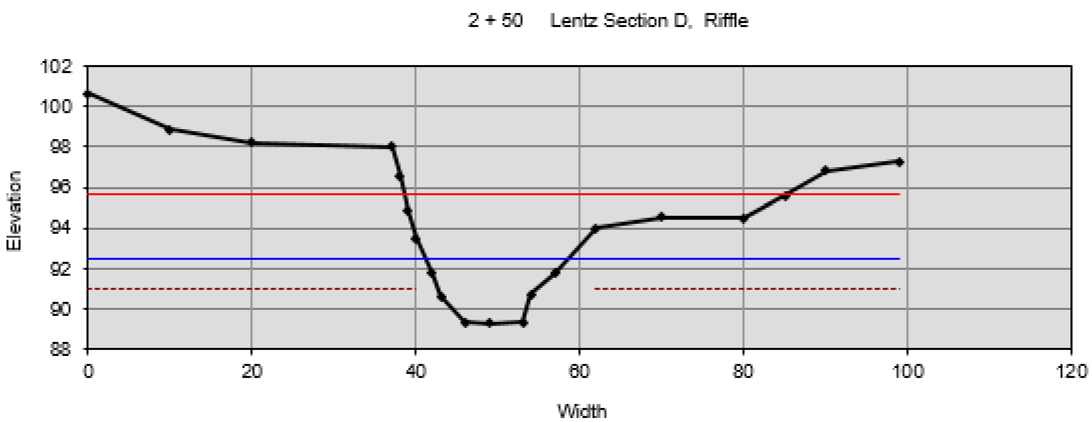
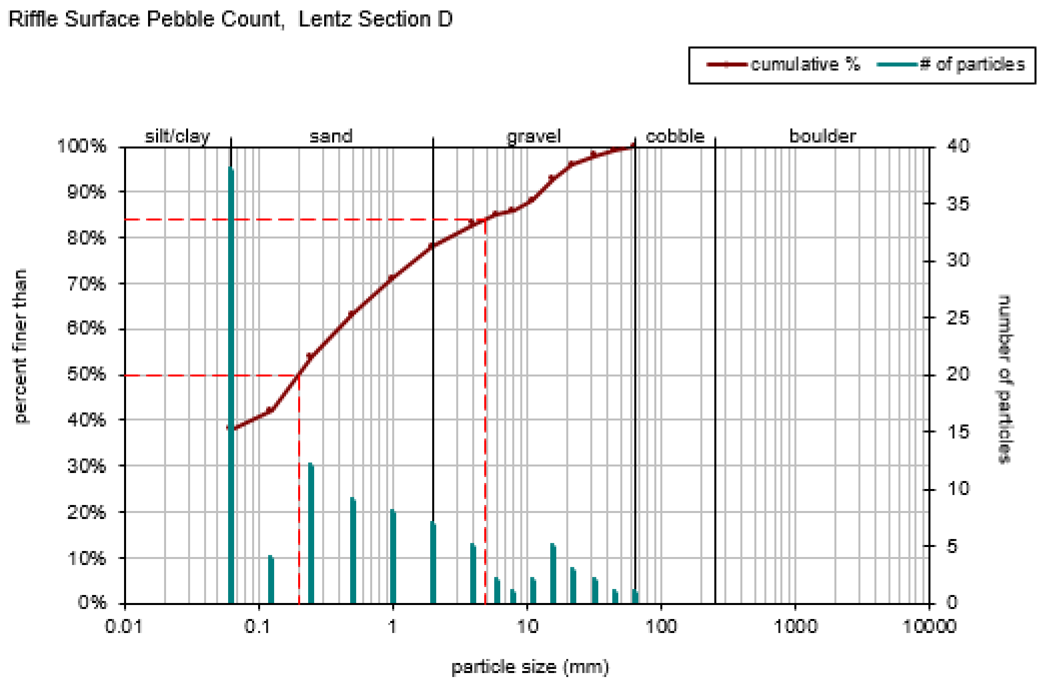


Figure F.9. Site C/D riffle pebble count.



Size (mm)	
D16	0.062
D35	0.062
D50	0.2
D65	0.59
D84	4.9
D95	20

Size Distribution	
mean	0.6
dispersion	13.9
skewness	0.32

Type	
silt/clay	38%
sand	40%
gravel	22%
cobble	0%
boulder	0%

Table F.10. Before and after comparisons for each site.

Site A (CG to MG)	BKF A	WDR	Slope	D50	D84
Before		17	0.0058	0.062	13
After	20.52	14.3	0.0085	0.3	12
Site B (CG to MG+)	BKF A	WDR	Slope	D50	D84
Before		16.7	0.0077	0.19	16
After	23.452	20.8	0.0098	0.081	26
Site C (NG to NG)	BKF A	WDR	Slope	D50	D84
Before		8.6	0.003	9	25
After	64.684	9.4	0.0085	0.062	0.2
Site D (NG to MG)	BKF A	WDR	Slope	D50	D84
Before		12.8	0.0062	9	25
After	22	11.3	0.002	0.077	1.4

Table F.11. Comparing sites A to C and C to D.

A vs B (MG vs MG+)	BKF A	WDR	Slope	D50	D84
A	20.52	14.3	0.0085	0.3	12
B	23.452	20.8	0.0098	0.081	26
C vs D (NG vs MG)					
C	64.684	9.4	0.0085	0.062	0.2
D	22	11.3	0.002	0.077	1.4

Table F.12. Channel and bed feature geomorphological measurement comparisons.

Section	Average Channel Width (ft)	Average Pool Depth (ft)	Average Pool Length (ft)	Width-depth Ratio
A (MG)	6.89	3.49	85.0	14.3
B (MG)	7.08	1.99	14.0	20.8
C (NG)	10.83	3.35	13.3	9.4
D (MG)	6.77	2.65	38.0	11.3

Table F.13. BEHI rating comparisons.

Section	BEHI Rating
A (MG)	24
B (MG)	28
C (NG)	41
D (MG)	35

Figure F.14. Comparison of width-depth ratios between all Sugarloaf sites.

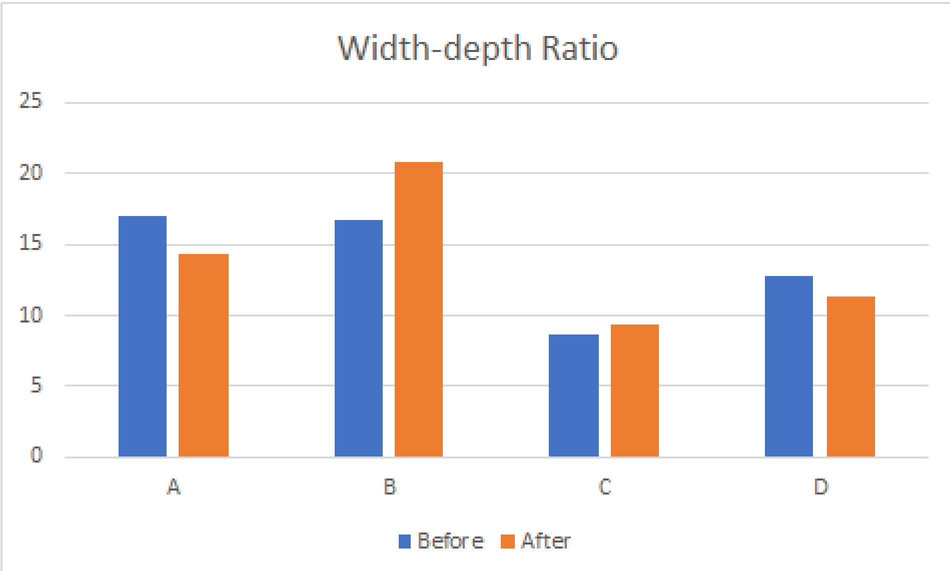


Figure F.15. Comparison of reach D50 between all Sugarloaf sites.

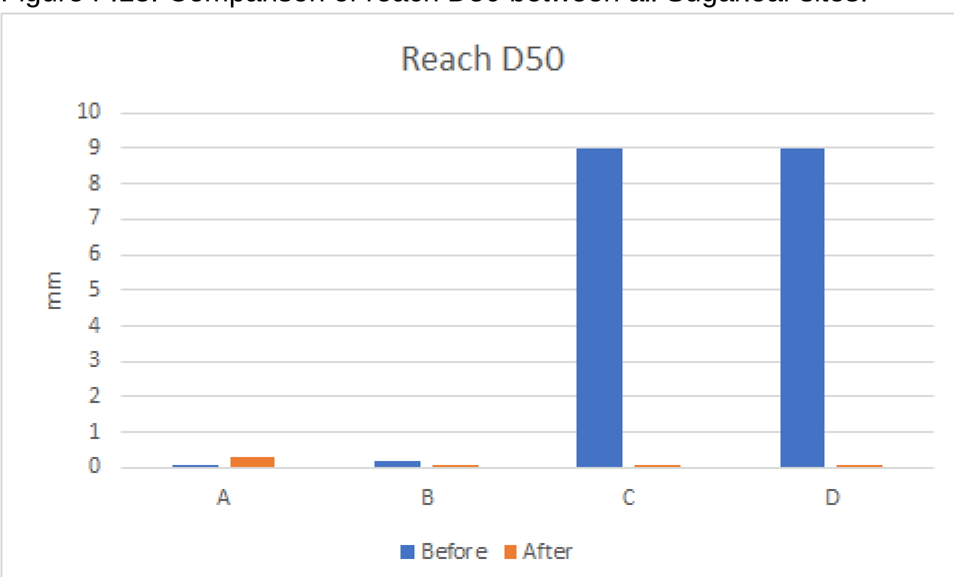
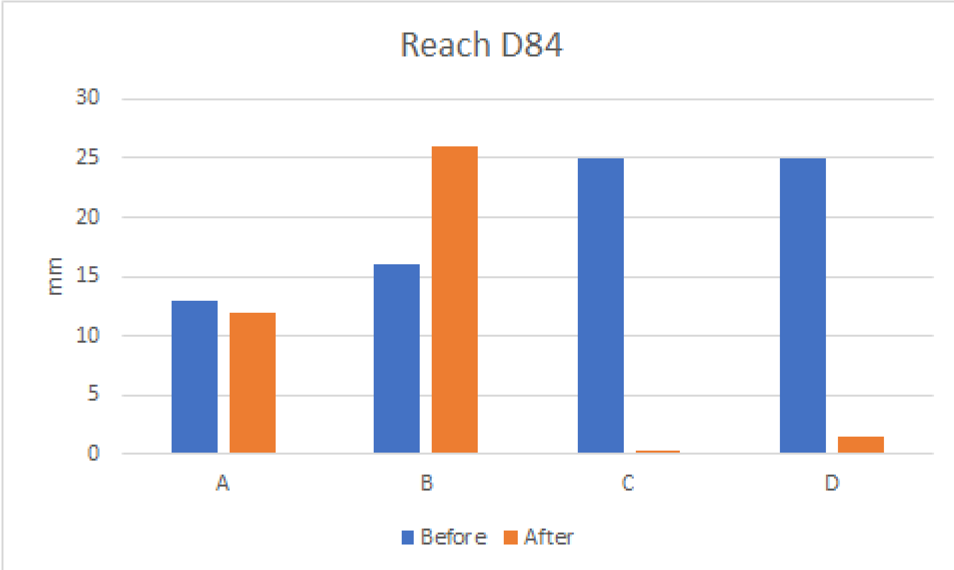


Figure F.16. Comparison of reach D84 between all Sugarloaf sites.



Appendix G: Elm Creek Data and Analysis

Figure G.1. Phase 1 longitudinal profile.

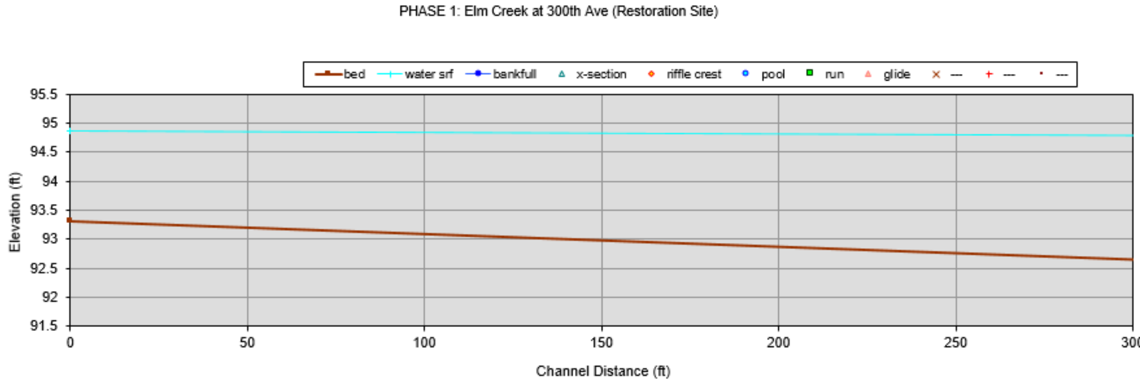


Figure G.2. Phase 1 riffle cross-section plot.

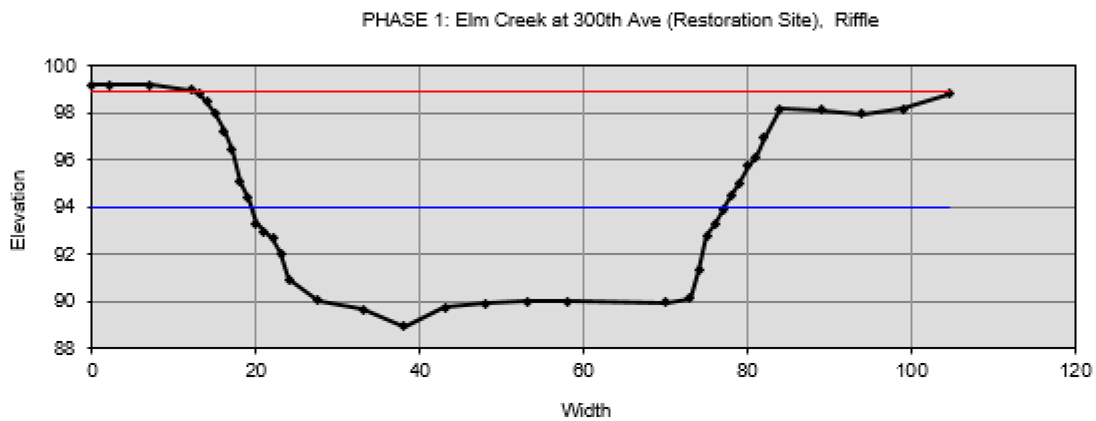
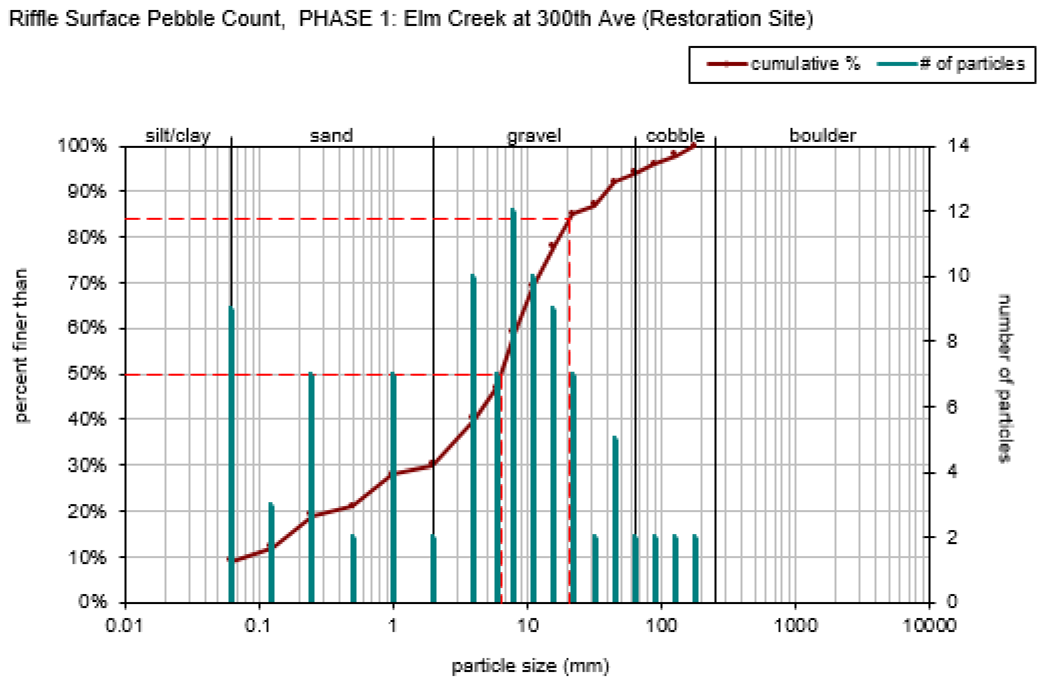


Figure G.3. Phase 1 riffle pebble count.



Size (mm)	
D16	0.19
D35	2.8
D50	6.4
D65	9.7
D84	21
D95	76

Size Distribution	
mean	2.0
dispersion	18.5
skewness	-0.35

Type	
silt/clay	9%
sand	21%
gravel	64%
cobble	6%
boulder	0%

Figure G.4. Phase 2 longitudinal profile.

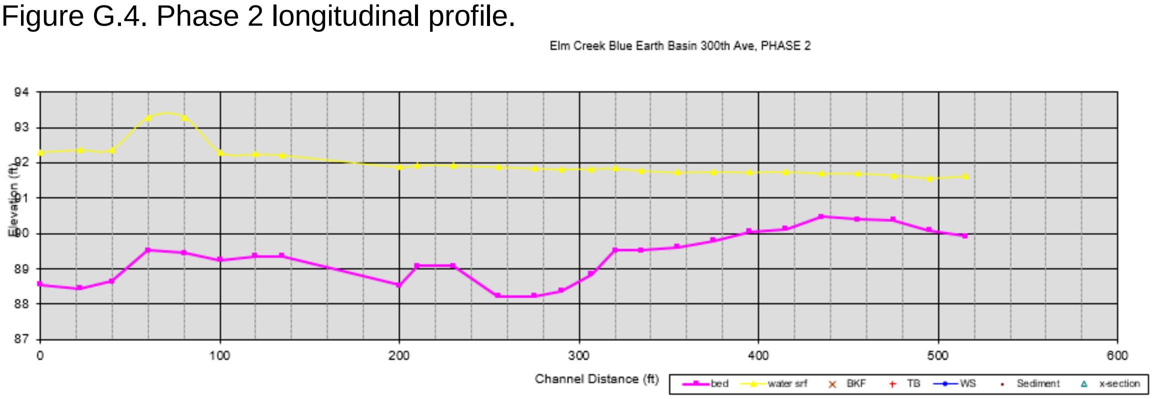


Figure G.5. Phase 2 run cross-section plot.

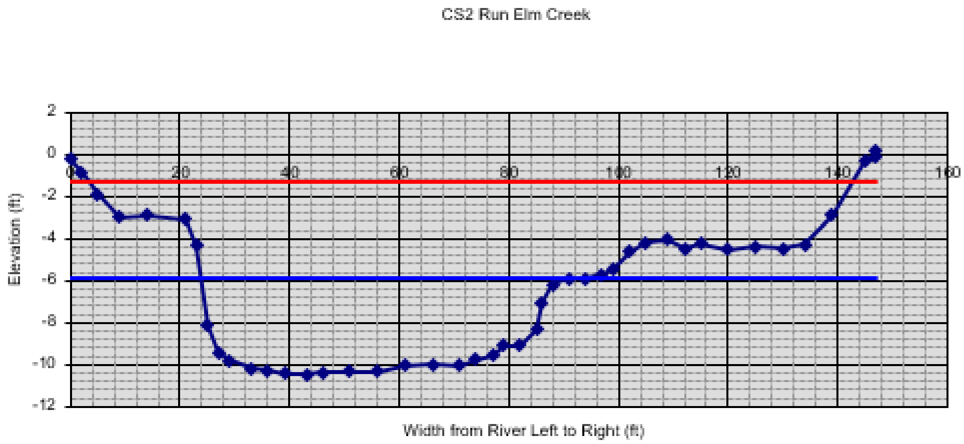
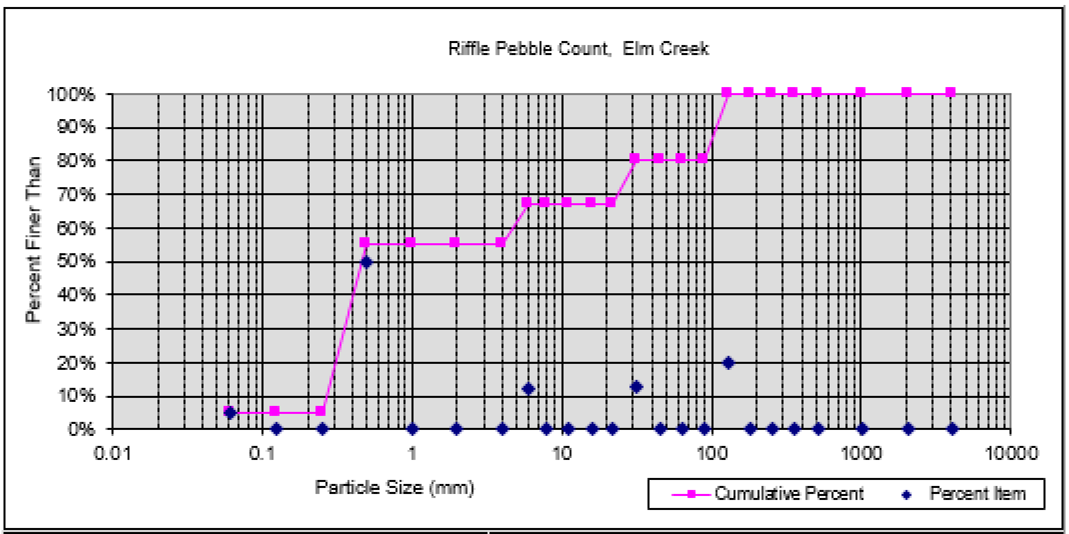


Figure G.6. Phase 2 riffle pebble count.



Size percent less than (mm)					Percent by substrate type					
D16	D35	D50	D84	D95	silt/clay	sand	gravel	cobble	boulder	bedrock
0.291	0.38	0.5	97	117	5%	50%	25%	20%	0%	0%

Figure G.7. Phase 3 riffle cross-section 1 plot.

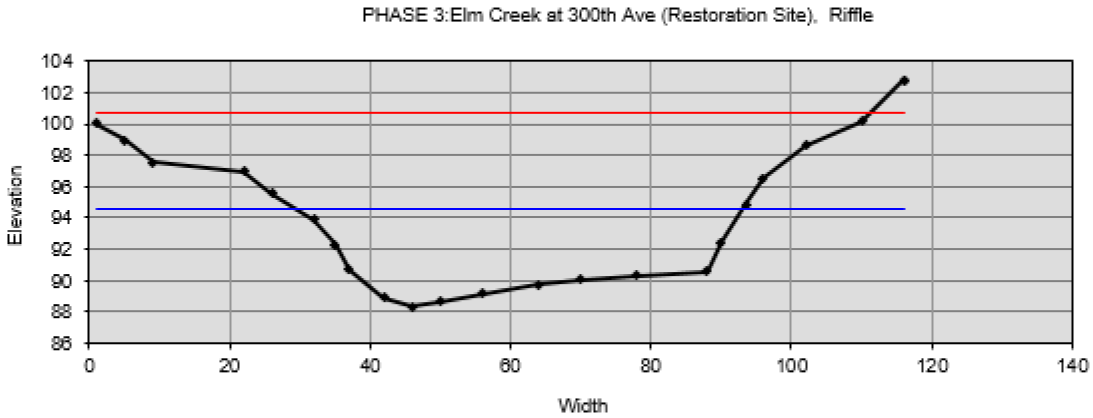


Figure G.8. Phase 3 riffle cross-section 2 plot.

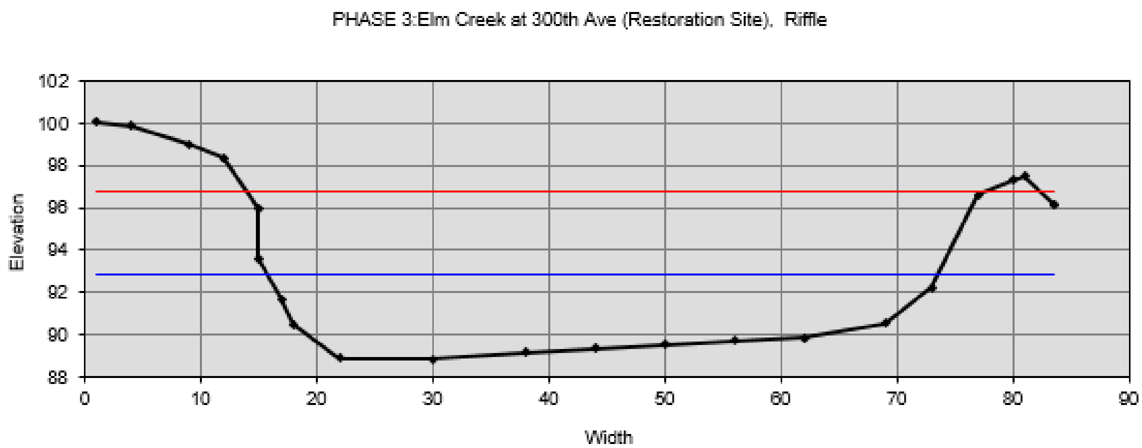
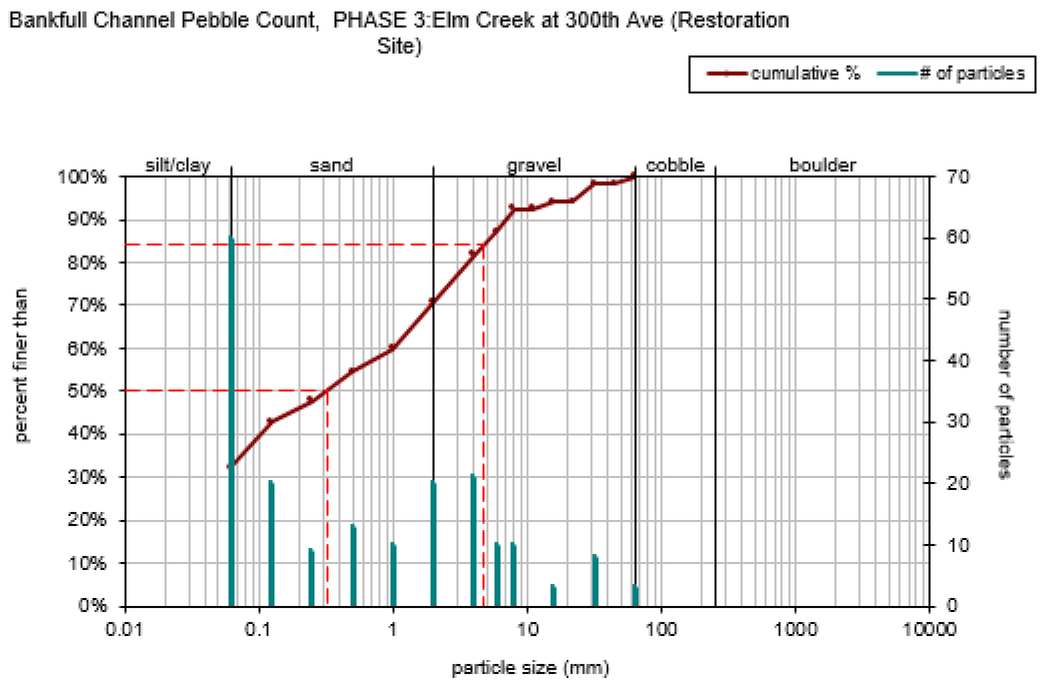


Figure G.9. Phase 3 bankfull channel pebble count.



Size (mm)	
D16	0.062
D35	0.075
D50	0.32
D65	1.4
D84	4.7
D95	24

Size Distribution	
mean	0.5
dispersion	9.9
skewness	0.17

Type	
silt/clay	32%
sand	39%
gravel	29%
cobble	0%
boulder	0%

Table G.10. Dataset for Elm creek sites.

Drainage_Area	BKF_W	Mean_BKF_D	Max_D	BKF_A	WDRatio	W_FPA	Ent_Ratio
P1	57.7	3.92	5	213.2	15.6	280	4.85268631
P2	70.6	3.53	4.58	249.29	20.01	412	5.83569405
Pre	65.6	4.47	5.4	293	14.7	500	7.62195122
P1and2	64.15	3.725	4.79	231.245	17.805	346	5.34419018
P3	60.51	3.685	5.075	224.565	16.68	439	7.25900162

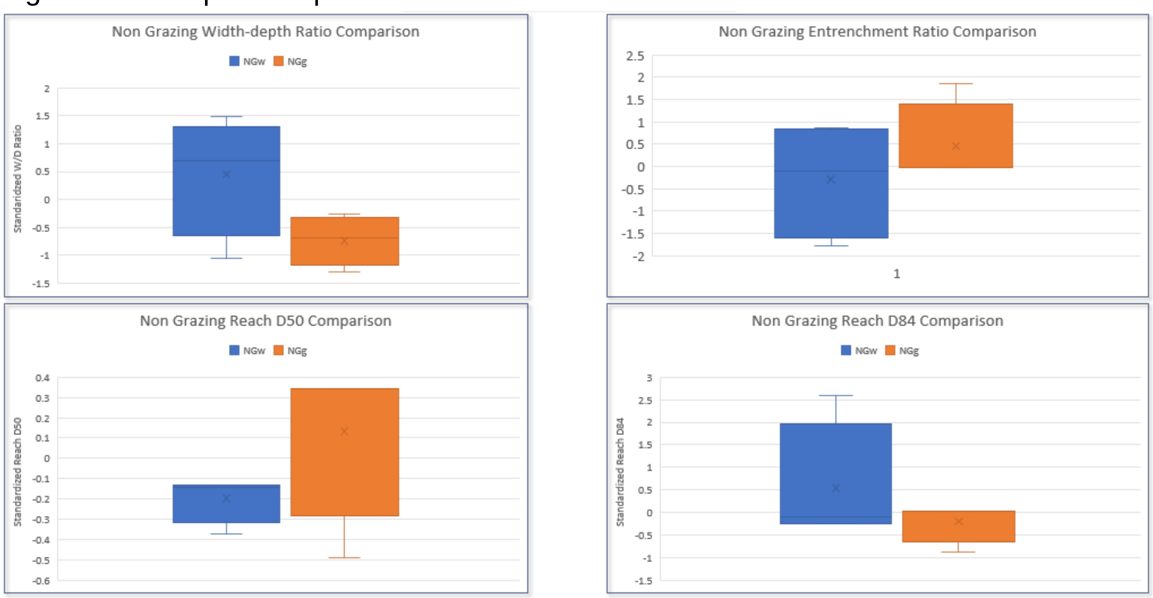
Hyd_Rad	WS_Slope	Valley_L	Channel_L	Sinuosity	ReachD50	ReachD84	RiffleD50	RiffleD84	BEHI_Rating
3.5	0.0011	140	141	1.00714286			6.4	21	
3.21001803	0.0013	397	665	1.33534137	4	22	0.5	97	35
4.2	0.00093				1.1	37			
3.35500901	0.0012	268.5	403	1.17124211	4	22	3.45	59	35
3.28156695	0.0001	489.9	569.1	1.16166565	0.32	4.7			25.5

Appendix H: Comparison of Non-Grazing Sites

Table H.1. Comparing dimensions between non-grazed wooded and non-grazed grassed sites.

WDR			EntR		
	NGw	NGg		NGw	NGg
	0.787582	-0.26426		0.783688	1.852748
	1.478572	-1.29599		0.857652	-0.01393
	0.599479	-0.52873		-1.78197	-0.01393
	-1.06466	-0.85625		-0.99935	-0.01393
Reach D50			Reach D84		
	NGw	NGg		NGw	NGg
	-0.14338	-0.4914		-0.24492	-0.89169
	-0.14338	0.342221		-0.24492	0.031034
	-0.12989	0.342221		2.598004	0.031034
	-0.3727	0.342221		0.04397	0.031034

Figure H.2. Graphical representations of the dimensions.



Appendix I: Regression Analysis

Table I.1. Summary of regression analyses.

Appendix I.2: Width-depth Ratio Regression Model

	** = p-value < 0.05		* = p-value < 0.1		x = p-value > 0.1											
	Dependent Variables															Sig if < 0.05
Independent Variable	Drainage_	BKF_W	Mean_BKI	Max_D	BKF_A	WDRatio	W_FPA	Ent_Ratio	Hyd_Rad	WS_Slope	Sinuosity	ReachD50	ReachD84	BEHI_Rating	Adj R2	Sig. F
WD Ratio 1							**						x		0.3631	0.0014
WD Ratio 2							**								0.3336	0.0010
Ent Ratio 1	**		x							**			*		0.3180	0.0113
Ent Ratio 2	**									**			*		0.3421	0.0044
BEHI Rating 1	x	x	x	x				x		x	x	*	x		0.1888	0.2091
BEHI Rating 2	**								*			**	*		0.3491	0.0149
D50 1						x		x		**	x		**		0.1990	0.0824
D50 2						x	**			*	x		**		0.2824	0.0320
D50 3		**						x		x	x		**		0.3304	0.0172
D50 4		x					x			x	x		x		0.3175	0.0204
D50 5		**													0.2492	0.0047
BKF W 1	**		**	**			x			x	x	x	**		0.9211	8.15E-10
BKF W 2	**		**	**			x					x	**		0.9232	3.05E-11
BKF W 3	**		**	**			x						**		0.9256	4.20E-12
BKF W 4	**		**	**									**		0.9229	1.03E-12

Table I.2.1: Summary of the regression analysis of flood-prone area width as a predictor of the width-depth ratio.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.599363642
R Square	0.359236775
Adjusted R Square	0.333606246
Standard Error	0.839000292
Observations	27

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	9.86614386	9.86614386	14.015972	0.000953718
Residual	25	17.59803726	0.703921491		
Total	26	27.46418112			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.062609214	0.161465722	-0.387755448	0.7014789	-0.395154094	0.2699357	-0.395154	0.2699357
W_FPA	0.608612482	0.162565822	3.743791119	0.0009537	0.273801904	0.9434231	0.2738019	0.9434231

RESIDUAL OUTPUT | PROBABILITY OUTPUT

Observation	*Predicted WDRatio*	*Residuals*	*Standard Residuals*		*Percentile*	*WDRatio*
1	-0.208683576	-1.04346137	-1.268326111		1.851851852	-1.463356
2	-0.551863297	-0.45838762	-0.557169627		5.555555556	-1.254128
3	-0.149704865	2.141319255	2.602771123		9.259259259	-1.252145
4	-0.439167285	0.48175024	0.58556687		12.96296296	-1.224387
5	-0.418121645	-0.7031626	-0.854693336		16.66666667	-1.121284
6	-0.520931297	-0.73319639	-0.891199377		20.37037037	-1.028096
7	-0.338097293	0.095165979	0.115674139		24.07407407	-1.010251
8	-0.448247461	-0.39347072	-0.478263218		27.77777778	-0.964648
9	0.007331256	0.411971915	0.500751395		31.48148148	-0.841718
10	-0.459661327	0.551812731	0.670727748		35.18518519	-0.670786
11	-0.501158578	-0.52693698	-0.640491297		38.88888889	-0.494739
12	-0.423467916	-0.07127112	-0.086629967		42.59259259	-0.478877
13	-0.475785003	-0.00309213	-0.003758482		46.2962963	-0.397585
14	-0.411544882	1.247223029	1.515998176		50	-0.242931
15	-0.339539938	-0.625108	-0.759818066		53.7037037	-0.020865
16	1.005895988	0.700204133	0.851097328		57.40740741	0.042583
17	1.379286387	-0.72602013	-0.882476648		61.11111111	0.0921514
18	0.246385973	1.616350449	1.964672135		64.81481481	0.4193032
19	0.44581039	0.128146344	0.155761735		68.51851852	0.4946472
20	0.415684574	-0.43654923	-0.530625099		72.22222222	0.5739567
21	1.184105042	-0.49514951	-0.601853662		75.92592593	0.6532663
22	1.056812861	0.345928349	0.420475515		79.62962963	0.6889555
23	0.547644135	-0.94522901	-1.148924791		83.33333333	0.8356781
24	-0.614957788	1.109605002	1.34872362		87.03703704	1.4027412
25	-0.571254139	-0.65313248	-0.793881783		90.74074074	1.7061001
26	-0.559415966	-0.90393965	-1.098737622		94.44444444	1.8627364
27	-0.559415966	-0.11137049	-0.1353707		98.14814815	1.9916144

Figure I.2.2: Regression plot of flood-prone area width as a predictor of width-depth ratio.

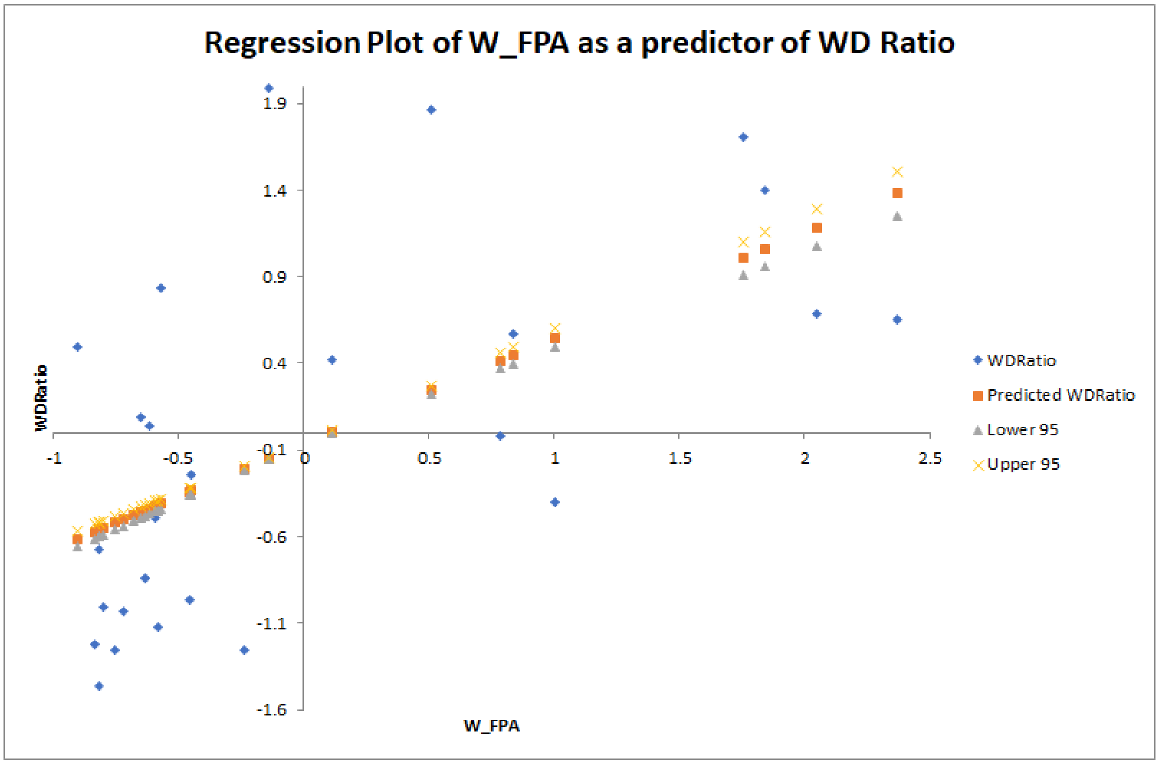
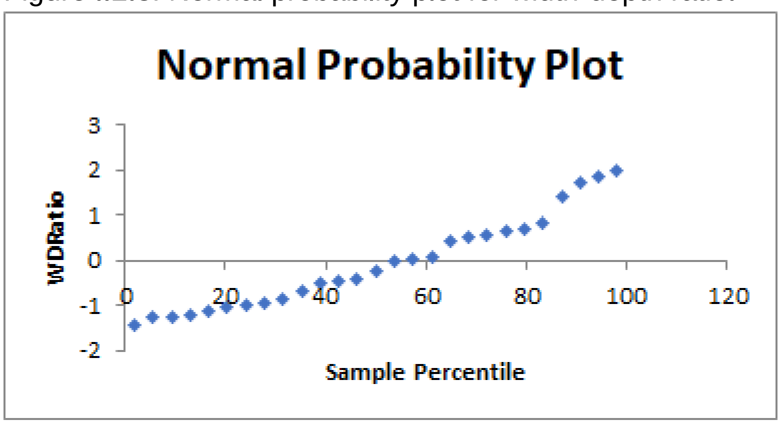


Figure I.2.3: Normal probability plot for width-depth ratio.



Appendix I.3: Bankfull Width Regression Model

Table I.3.1: Summary of the regression analysis of drainage area, mean bankfull depth, maximum bankfull depth, and reach D84 as predictors of bankfull width.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.966818309
R Square	0.934737642
Adjusted R Square	0.922871759
Standard Error	0.243875899
Observations	27

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	18.7407696	4.6851924	78.775227	1.032E-12
Residual	22	1.308459995	0.059475454		
Total	26	20.04922959			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.008168443	0.052562415	-0.155404643	0.8779194	-0.117176221	0.1008393	-0.117176	0.1008393
Mean_BKF_D	-0.474864453	0.085780404	-5.535815086	1.455E-05	-0.652762122	-0.296967	-0.652762	-0.296967
Max_D	0.337109558	0.071112741	4.740494472	9.894E-05	0.189630758	0.4845884	0.1896308	0.4845884
ReachD84	0.232392229	0.07690005	3.022003614	0.0062664	0.072911286	0.3918732	0.0729113	0.3918732
Drainage_Area	0.98048402	0.079722978	12.29863765	2.476E-11	0.815148683	1.1458194	0.8151487	1.1458194

RESIDUAL OUTPUT

Observation	*Predicted BKF_W*	*Residuals*	*Standard Residuals*
1	-0.627831813	-0.0800095	-0.356654756
2	-0.645937474	-0.26965507	-1.202029281
3	-0.049057998	0.204876276	0.913267748
4	-0.597559081	0.353076204	1.573891891
5	-0.680648341	0.083720284	0.373196141
6	-0.643329691	-0.16303863	-0.726769969
7	-0.211755746	-0.18980733	-0.846095589
8	-0.610601001	-0.15860856	-0.707022256
9	-0.433510976	0.236884074	1.055947469
10	-0.203567751	0.007503861	0.033449621
11	-0.606351458	0.020683631	0.092200489
12	-0.329441889	-0.03102135	-0.138282476
13	-0.83319615	0.4378262	1.951678132
14	-0.580134958	0.401524422	1.789857334
15	-0.605746282	-0.08464168	-0.377303396
16	2.253138329	0.162607986	0.724850296
17	0.022707481	0.028390664	0.126555784
18	0.625061025	-0.15733439	-0.701342441
19	-0.115787858	-0.03579813	-0.159575697
20	2.060433295	-0.05568535	-0.24822609
21	1.813249544	-0.122662	-0.546784881
22	-0.068923626	0.277664982	1.237734683
23	-0.276940564	0.181655726	0.809758549
24	-0.774986207	-0.02462598	-0.109774113
25	-0.747795338	-0.353591	-1.576186654
26	-0.503424164	-0.23819784	-1.061803785
27	-0.451763407	-0.43173749	-1.924536751

PROBABILITY OUTPUT

Percentile	*BKF_W*
1.851851852	-1.101386
5.555555556	-0.915593
9.259259259	-0.883501
12.96296296	-0.806368
16.66666667	-0.799612
20.37037037	-0.76921
24.07407407	-0.741622
27.77777778	-0.707841
31.48148148	-0.690388
35.18518519	-0.596928
38.88888889	-0.585668
42.59259259	-0.401563
46.2962963	-0.39537
50	-0.360463
53.7037037	-0.244483
57.40740741	-0.196627
61.11111111	-0.196064
64.81481481	-0.178611
68.51851852	-0.151586
72.22222222	-0.095285
75.92592593	0.0510981
79.62962963	0.1558183
83.33333333	0.2087414
87.03703704	0.4677266
90.74074074	1.6905875
94.44444444	2.0047479
98.14814815	2.4157463

Figure I.3.2: Regression plot of drainage area, mean bankfull depth, maximum bankfull depth, and reach D84 as predictors of bankfull width.

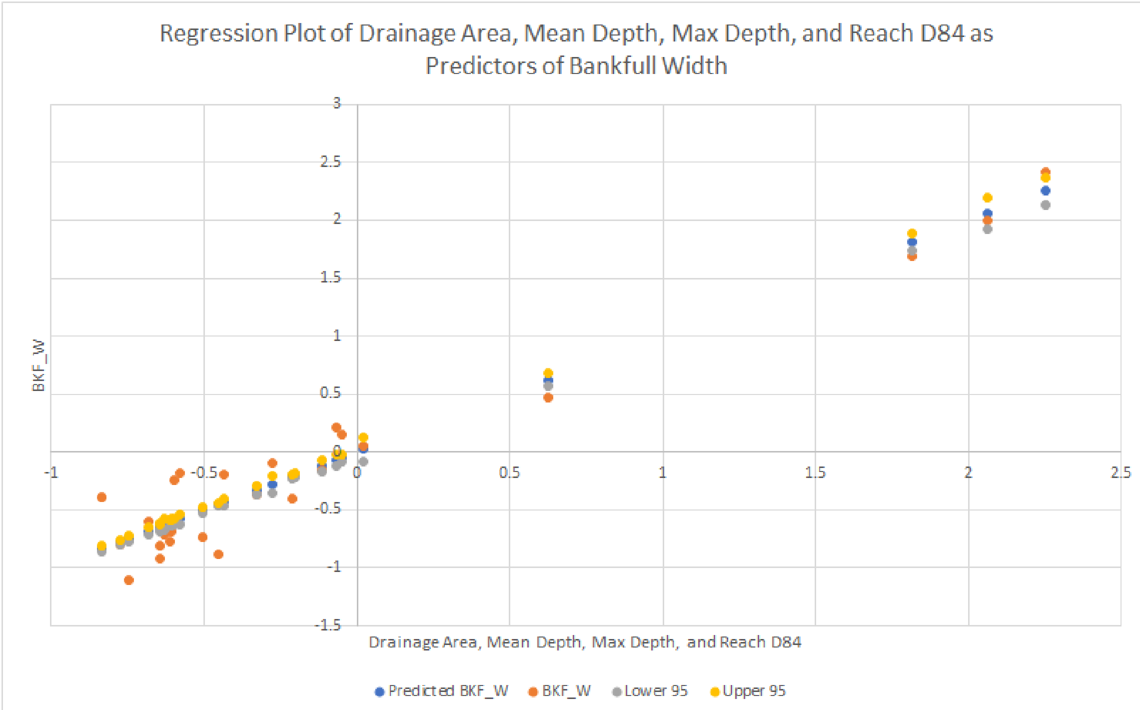
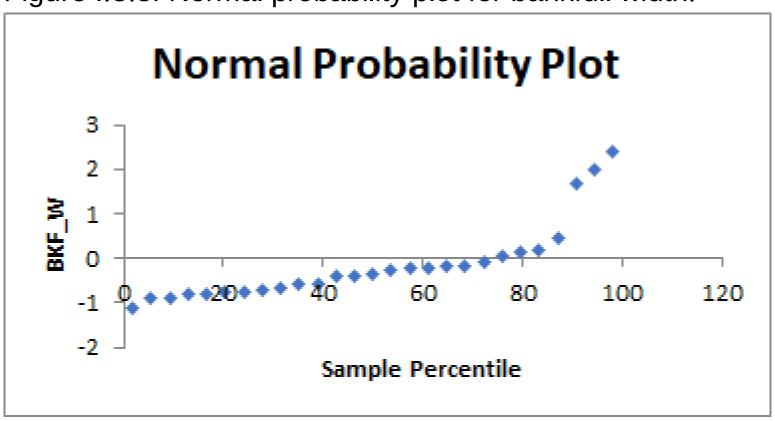


Figure I.3.3: Normal probability plot for bankfull width.



Appendix I.4: Reach D50 Regression Model

Table I.4.1: Summary of the regression analysis of bankfull width as a predictor of reach D50.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.52734628
R Square	0.278094099
Adjusted R Square	0.249217863
Standard Error	0.289443874
Observations	27

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.806826055	0.806826055	9.6305522	0.004704534
Residual	25	2.094443907	0.083777756		
Total	26	2.901269962			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.214075082	0.056450732	-3.792246314	0.0008431	-0.330337541	-0.097813	-0.330338	-0.097813
BKF_W	0.200604704	0.064642109	3.103313101	0.0047045	0.067471788	0.3337376	0.0674718	0.3337376

RESIDUAL OUTPUT / PROBABILITY OUTPUT

Observation	*Predicted ReachD50*	*Residuals*	*Standard Residuals*	*Percentile*	*ReachD50*
1	-0.356071379	0.029642518	0.10444013	1.851851852	-0.406635
2	-0.397747254	-0.00077702	-0.002737678	5.555555556	-0.399876
3	-0.182817202	-0.21570707	-0.760005408	9.259259259	-0.398524
4	-0.263119497	-0.13540477	-0.477074585	12.96296296	-0.398524
5	-0.333821658	-0.03316087	-0.116836418	16.66666667	-0.398524
6	-0.375836361	0.008853832	0.031194898	20.37037037	-0.398074
7	-0.294630524	-0.072352	-0.254919394	24.07407407	-0.366983
8	-0.368382139	0.041953278	0.147814897	27.77777778	-0.366983
9	-0.253519363	0.066775357	0.235271068	31.48148148	-0.366983
10	-0.25340642	-0.07302244	-0.257281555	35.18518519	-0.366983
11	-0.331562803	0.027663757	0.097468317	38.88888889	-0.326429
12	-0.286385703	-0.04004316	-0.14108493	42.59259259	-0.326429
13	-0.293388154	-0.03304071	-0.116413044	46.2962963	-0.326429
14	-0.249905195	0.063161189	0.222537192	50	-0.326429
15	-0.352570154	0.165826148	0.584258876	53.7037037	-0.326429
16	0.270534993	1.097278255	3.866064364	57.40740741	-0.303899
17	-0.203824554	-0.19424912	-0.684402154	61.11111111	-0.299393
18	-0.120246919	-0.17914616	-0.631189578	64.81481481	-0.290381
19	-0.244483943	-0.15539212	-0.547496424	68.51851852	-0.290381
20	0.188086786	-0.47846794	-1.685796519	72.22222222	-0.285875
21	0.125064732	-0.41544589	-1.463749544	75.92592593	-0.186744
22	-0.172200584	-0.23443442	-0.825987895	79.62962963	-0.186744
23	-0.233189668	-0.05268553	-0.185628058	83.33333333	-0.186744
24	-0.374481048	0.007498519	0.026419695	87.03703704	-0.128166
25	-0.435018361	0.306851874	1.081137889	90.74074074	-0.128166
26	-0.362847944	0.234681458	0.826858289	94.44444444	-0.128166
27	-0.391309517	0.26314303	0.927137568	98.14814815	1.3678132
27	-0.361888258	0.233721771	0.86827025	98.14814815	1.3678132

Figure I.4.2: Regression plot of bankfull width as a predictor of reach D50.

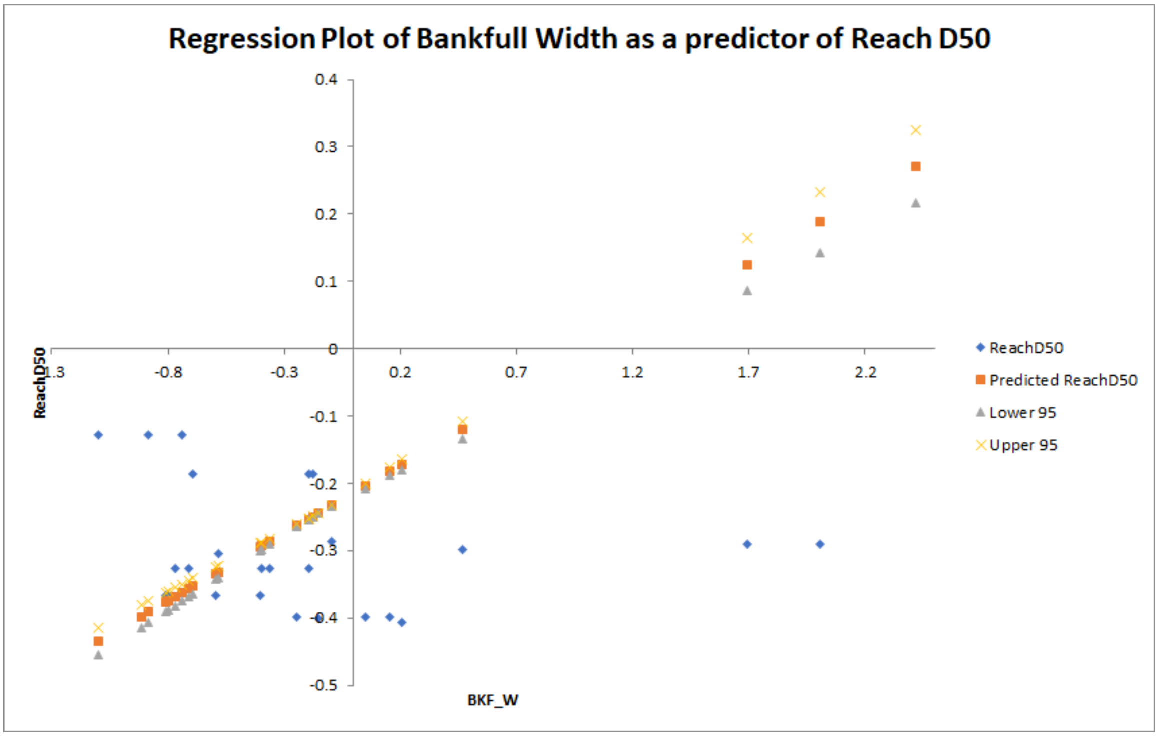
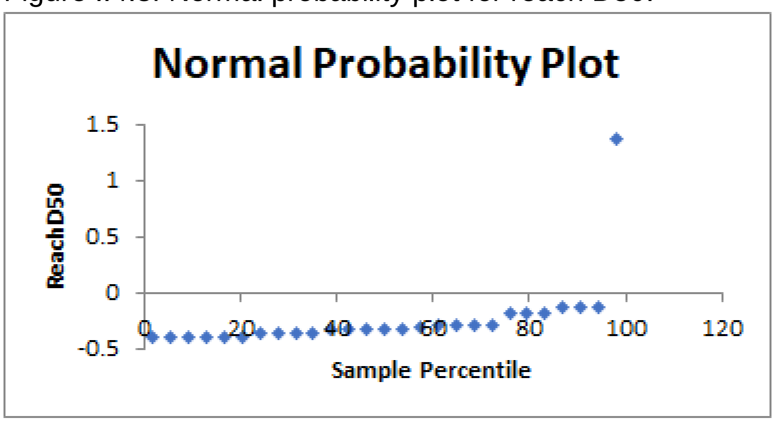


Figure I.4.3: Normal probability plot for reach D50.



Appendix I.5: Entrenchment Ratio Regression Model

Table I.5.1: Summary of the regression analysis of drainage area, slope, and reach D84 as predictors of the entrenchment ratio.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.644362897
R Square	0.415203543
Adjusted R Square	0.342103985
Standard Error	0.825144595
Observations	28

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	11.60186152	3.867287173	5.6799734	0.004368753
Residual	24	16.34072646	0.680863602		
Total	27	27.94258798			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.071314276	0.159664389	0.446651107	0.6591314	-0.258216826	0.4008454	-0.258217	0.4008454
Drainage_Area	0.583257081	0.193913911	3.007814539	0.0060915	0.183038439	0.9834757	0.1830384	0.9834757
WS_Slope	0.70468995	0.189858221	3.711664131	0.0010881	0.31284184	1.0965381	0.3128418	1.0965381
ReachD84	-0.398379524	0.204817109	-1.945050031	0.0635756	-0.82110126	0.0243422	-0.821101	0.0243422

RESIDUAL OUTPUT

Observation	*Predicted Ent_Ratio*	*Residuals*	*Standard Residuals*
1	-0.342293789	1.610615464	2.070322808
2	-0.227093039	-0.41059638	-0.527790196
3	-0.227093039	-0.12454279	-0.160090218
4	-0.227093039	-0.78693699	-1.011547224
5	-0.479861729	0.078307594	0.100658414
6	-0.479861729	-0.1686795	-0.216824572
7	-0.479861729	0.149061365	0.191606967
8	-0.342293789	0.144319522	0.185511691
9	-0.373493519	1.200363752	1.542975657
10	-0.290264916	-0.85789343	-1.102756289
11	-0.138613749	-0.7751456	-0.996390293
12	-0.170774336	-0.63880768	-0.821138343
13	-0.170774336	-0.85150307	-1.094541968
14	-0.373493519	-0.58801377	-0.755846664
15	-0.373493519	0.701180705	0.901314087
16	0.662996358	-0.47174065	-0.606386473
17	-0.132917432	1.099537744	1.413371547
18	1.022532777	0.171932878	0.221006545
19	1.280216182	-0.24595589	-0.316157458
20	0.079399625	2.317075737	2.978423375
21	1.084278568	-0.31288455	-0.402189119
22	1.084278568	-0.23752464	-0.305319729
23	1.774710397	0.085915258	0.110437483
24	-0.999294849	-0.84337904	-1.084099153
25	-0.479861729	-0.5654215	-0.726806029
26	-0.148179349	0.106905152	0.137418384
27	-0.148179349	0.106905152	0.137418384
28	-0.148179349	0.106905152	0.137418384

PROBABILITY OUTPUT

Percentile	*Ent_Ratio*
1.785714286	-1.842674
5.357142857	-1.148158
8.928571429	-1.045283
12.5	-1.022277
16.07142857	-1.01403
19.64285714	-0.961507
23.21428571	-0.913759
26.78571429	-0.809582
30.35714286	-0.648541
33.92857143	-0.637689
37.5	-0.401554
41.07142857	-0.351636
44.64285714	-0.3308
48.21428571	-0.197974
51.78571429	-0.041274
55.35714286	-0.041274
58.92857143	-0.041274
62.5	0.1912557
66.07142857	0.3276872
69.64285714	0.771394
73.21428571	0.8268702
76.78571429	0.8467539
80.35714286	0.9666203
83.92857143	1.0342603
87.5	1.1944657
91.07142857	1.2683217
94.64285714	1.8606257
98.21428571	2.3964754

Figure I.5.2: Regression plot of drainage area, slope, and reach D84 as predictors of entrenchment ratio.

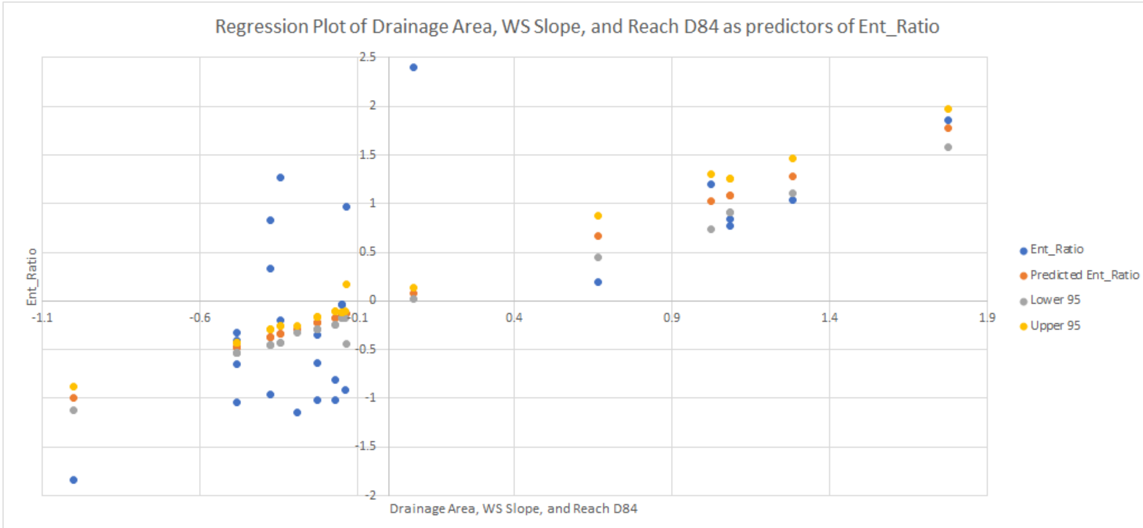
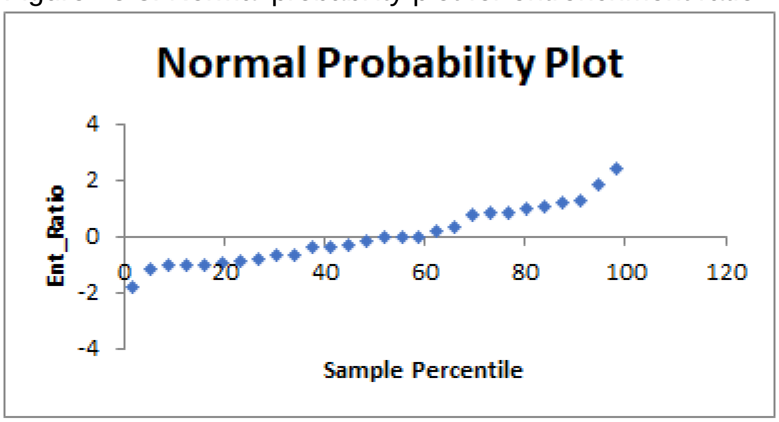


Figure I.5.3: Normal probability plot for entrenchment ratio.



Appendix I.6: BEHI Rating Regression Model

Table I.6.1: Summary of the regression analysis of drainage area, hydraulic radius, reach D50, and reach D84 as predictors of the BEHI rating.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.679908252
R Square	0.462275232
Adjusted R Square	0.349070017
Standard Error	0.80680232
Observations	24

L = (b0 + (b1*xi)) - tvalue from chart*stderror*sqrt((1/n)*((xi-xbar)^2)/sumx)

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	10.63233033	2.658082581	4.0835154	0.014860699
Residual	19	12.36766967	0.650929983		
Total	23	23			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.244032963	0.218191815	1.118433168	0.277324	-0.212647755	0.7007137	-0.212648	0.7007137
Drainage_Area	-0.951510437	0.3013385	-3.157613236	0.0051835	-1.582219167	-0.320802	-1.582219	-0.320802
Hyd_Rad	0.613804269	0.311586618	1.969931422	0.0635992	-0.038354017	1.2659626	-0.038354	1.2659626
ReachD50	1.43679167	0.634898842	2.263024556	0.0355387	0.107933121	2.7656502	0.1079331	2.7656502
ReachD84	-0.473887152	0.250843395	-1.889175321	0.0742289	-0.998908412	0.0511341	-0.998908	0.0511341

RESIDUAL OUTPUT

Observation	*Predicted BEHI_Rating*	*Residuals*	*Standard Residuals*
1	0.81853004	-0.02300204	-0.031367965
2	-0.20851704	0.623185146	0.849839813
3	-0.124041014	-0.52107493	-0.710591739
4	0.242021761	-0.8871377	-1.209792855
5	0.372643649	-1.33238298	-1.816975432
6	0.267048618	-0.24979953	-0.34065251
7	0.069937893	0.493762346	0.673345477
8	0.241277202	-1.86338156	-2.541100098
9	0.496468909	0.41497297	0.565900123
10	0.124849333	0.488528283	0.666207766
11	0.657729458	0.369626301	0.504060709
12	0.593686224	0.152164398	0.207507133
13	0.55848788	1.379619794	1.881392447
14	0.362715203	-0.34546611	-0.471113375
15	0.749896984	-0.15307849	-0.20875369
16	0.224361276	0.074392951	0.101449934
17	-1.593844695	0.733460121	1.00022219
18	-0.928863965	-0.59388564	-0.80988397
19	-0.371092743	0.66984697	0.913472708
20	-0.919914158	0.30791647	0.419906791
21	-1.570808849	-0.3659189	-0.49900491
22	0.348606298	0.943695473	1.286920891
23	-0.657107873	-0.50134096	-0.683680466
24	0.245929611	0.185297621	0.252691029

PROBABILITY OUTPUT

Percentile	*BEHI_Rating*
2.083333333	-1.936728
6.25	-1.622104
10.41666667	-1.52275
14.58333333	-1.158449
18.75	-0.959739
22.91666667	-0.860385
27.08333333	-0.645116
31.25	-0.645116
35.41666667	-0.611998
39.58333333	0.0172491
43.75	0.0172491
47.91666667	0.2987542
52.08333333	0.2987542
56.25	0.4146681
60.41666667	0.4312272
64.58333333	0.5637002
68.75	0.5968185
72.91666667	0.6133776
77.08333333	0.7458506
81.25	0.795528
85.41666667	0.9114419
89.58333333	1.0273558
93.75	1.2923018
97.91666667	1.9381077

Figure I.6.2: Regression plot of drainage area, hydraulic radius, reach D50, and reach D84 as predictors of the BEHI rating.

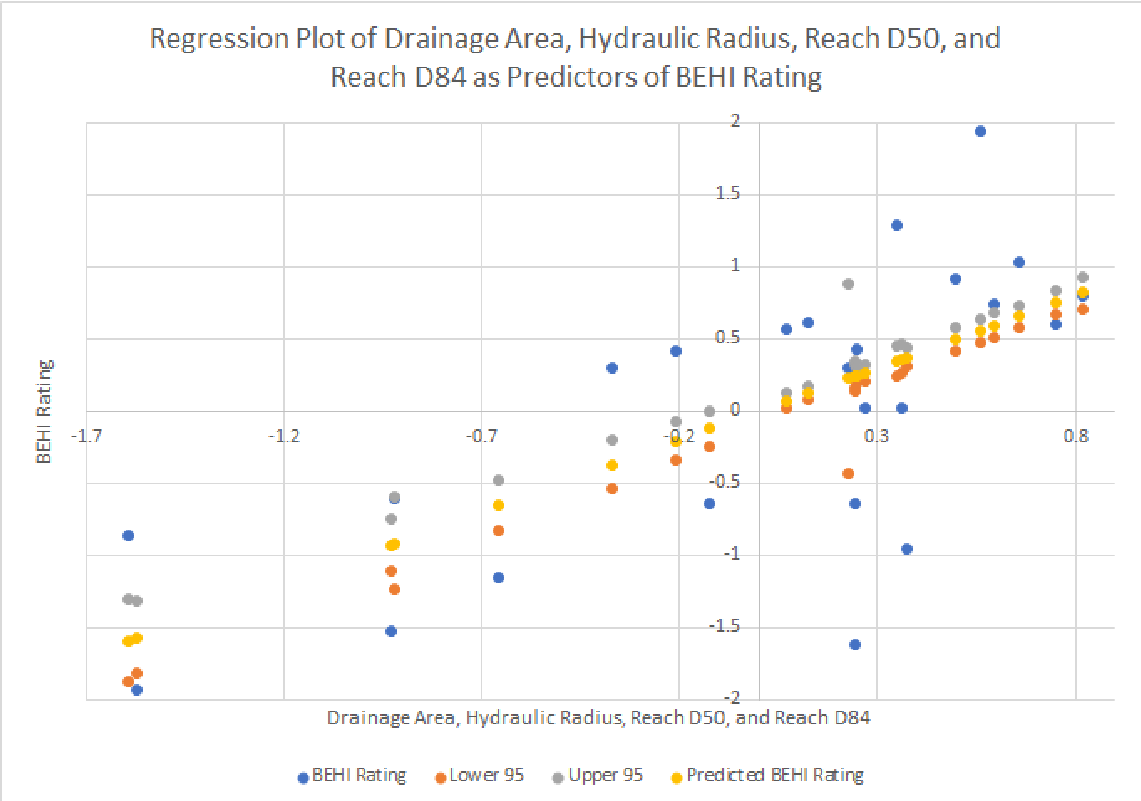
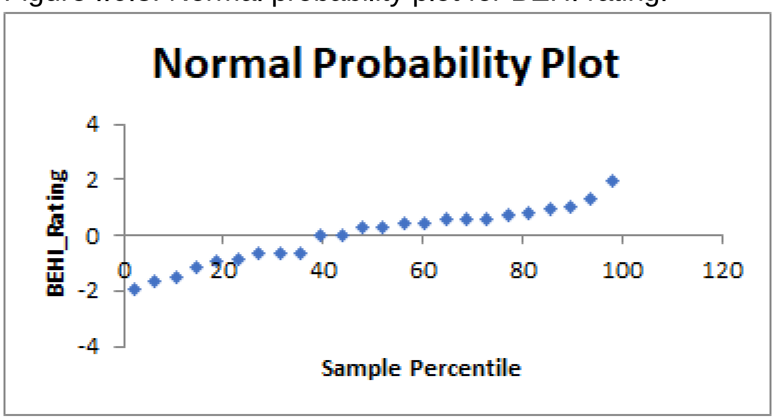


Figure I.6.3: Normal probability plot for BEHI rating.



Appendix J: Photos

Appendix J.1: Dobbins Creek Sites

Figure J.1.1. Map of reaches for pebble counts to better place photos with locations.

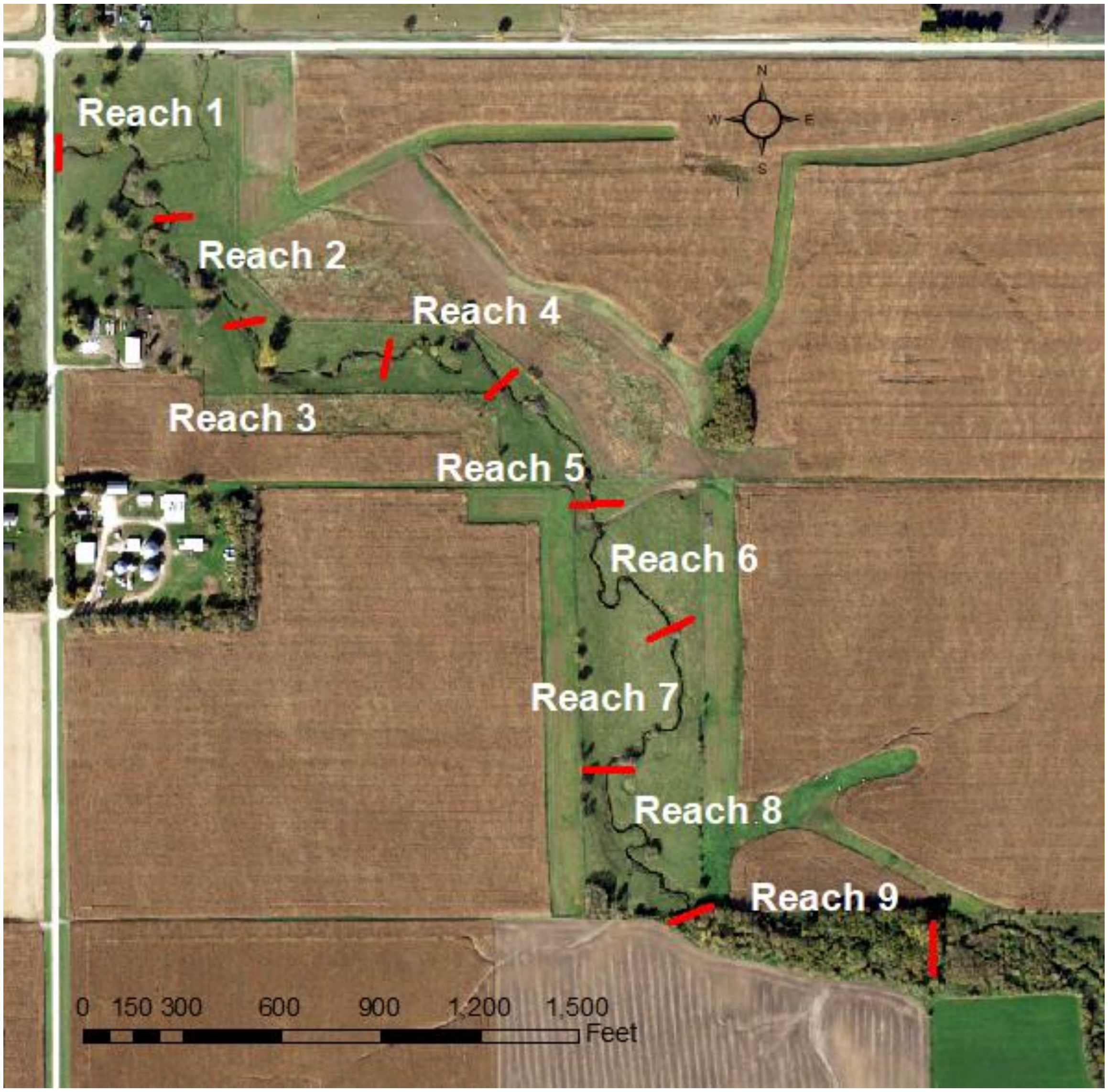


Photo J.1.2. Summer view of the northern section from 600th Ave.

Photo J.1.3. Summer view along the northern section (Reach 3).

Photo J.1.4. Summer view of a bank in the northern section (Reach 2).

Photo J.1.5. Summer view of a bank in the middle section (Reach 4).

Photo J.1.6. Summer view of a bank in the middle section (Reach 5).

Photo J.1.7. Summer view of a channel in the middle section (Reach 7).

Photo J.1.8. Summer view of the horseshoe bend in the middle section (Reach 7 and 8).

Photo J.1.9. Summer view down the sandbar towards the middle section (Reach 8).

Photo J.1.20. Summer view back up the middle section from the southern (Reach 8).

Photo J.1.11. Summer view at the entrance to the wooded southern section (Reach 9).

Photo J.1.12. Man-made riprap on the bank of the wooded southern section (Reach 9).

Photo J.1.13. Fall view of the channel in the wooded southern section (Reach 9).

Photo J.1.14. Fall view of the channel in the middle section (Reach 6).

Photo J.1.15. Fall view of a bank in the middle section (Reach 8).

Photo J.1.16. Fall view of the channel in the middle section (Reach 6).

Photo J.1.17. Winter view of the channel in the middle section (Reach 6).

Appendix J.2: Sugarloaf Creek Sites

Figure J.2.1. Map of the four sites (Cristina Lopez-Barrios, 2011).

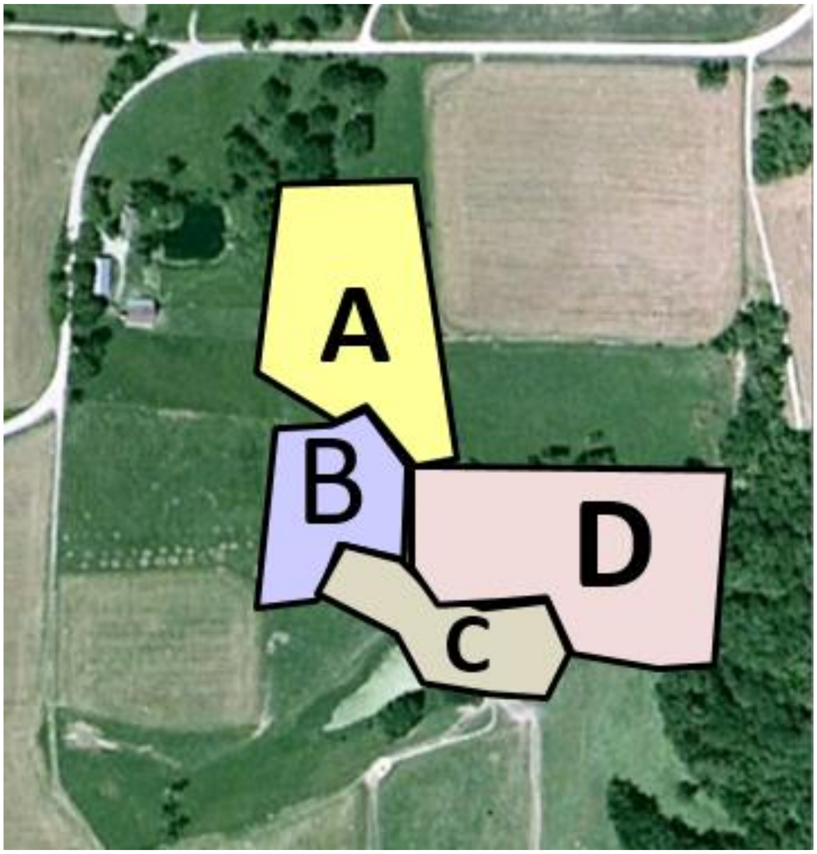


Photo J.2.2. Before management changes (2004) in site A.

Photo J.2.3. After management changes (2010) in site A.

Photo J.2.4. Before management changes (2004) in site B.

Photo J.2.5. After management changes (2010) in site B.

Photo J.2.6. Before management changes (2005) in site C.

Photo J.2.7. After management changes (2010) in site C.

Photo J.2.8. Before management changes (2005) in site D.

Photo J.2.9. After management changes (2010) in site D.

Appendix J.3: Elm Creek Sites

Figure J.3.1. Map of the Elm Creek sites.

Photo J.3.2. View towards Phase 1 from the 300th Ave bridge.

Photo J.3.3. View of the grazing that occurs on the banks in Phase 1.

Photo J.3.4. Fall view of the Phase 1 section of Elm Creek.

Photo J.3.5. View looking north towards Phase 2 before restoration (2007).

Photo J.3.6. View from the left bank at Phase 2 before restoration (2007).

Photo J.3.7. View of Phase 2 during restoration (2007).

Photo J.3.8. View of Phase 2 after restoration (2007).

Photo J.3.9. View of Phase 2 after restoration (2008).

Photo J.3.10. View of Phase 2 after restoration (2018).

Photo J.3.11. View of Phase 3 before restoration (2007).

Photo J.3.12. View of Phase 3 during restoration (2007).

Photo J.3.13. View of Phase 3 during restoration (2007).

Photo J.3.14. View of Phase 3 during restoration (2007).

Photo J.3.15. View of Phase 3 after restoration (2008).

Photo J.3.16. View of Phase 3 after restoration (2008).

Photo J.3.17. View of Phase 3 after restoration (2018).